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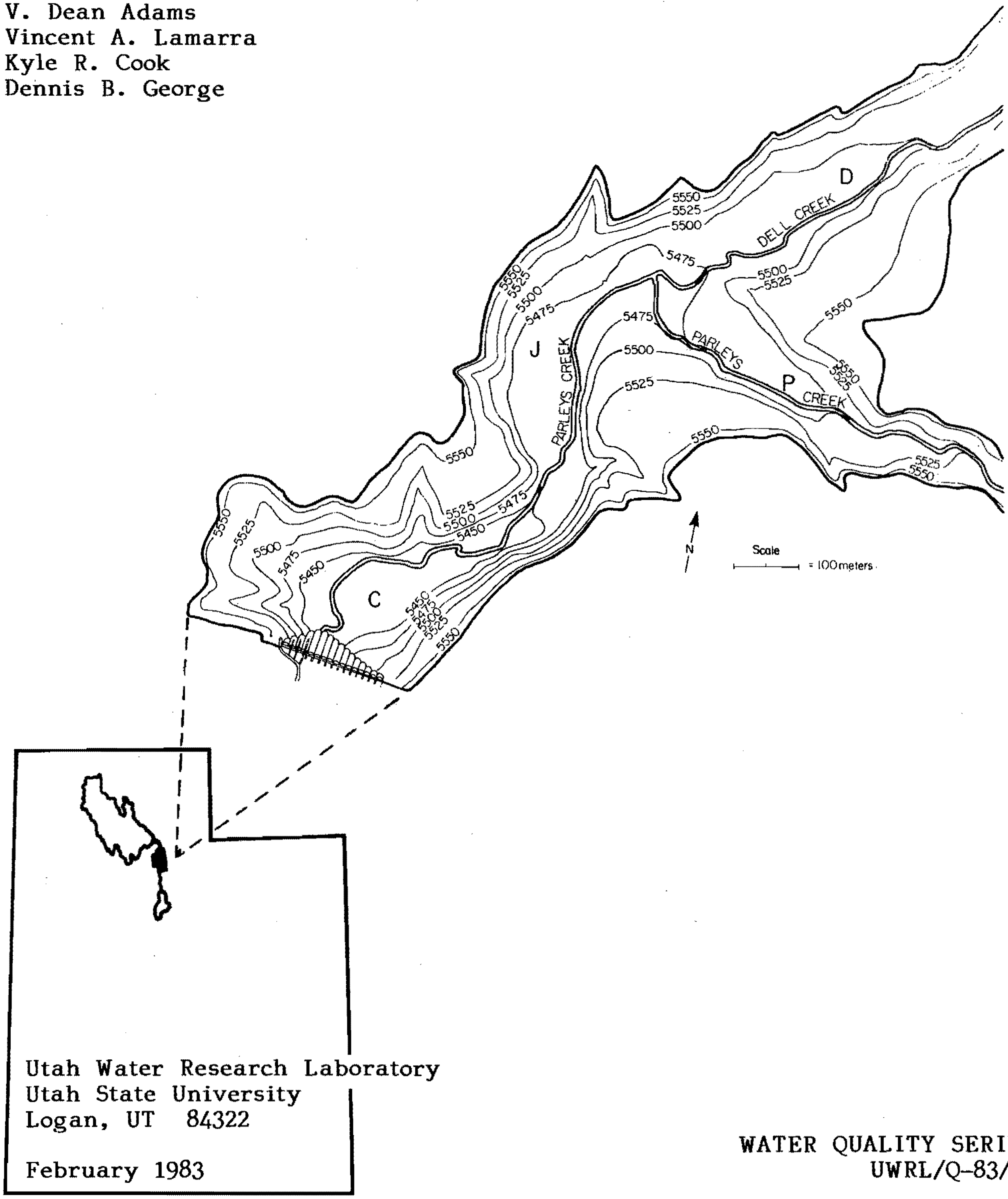

Utah Water Research Laboratory
Utah State University
Logan, UT 84322

February 1983

WATER QUALITY SERIES
UWRL/Q-83/01

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ABSTRACT

The degree and possible causes of eutrophication in Mt. Dell Reservoir, a small water supply reservoir in Parleys Canyon above Salt Lake City, were examined with a number of limnological studies. These studies described external (incoming stream flow) and internal (sediment) nutrient sources, general limnology, nutrient limitations, and trophic state. A monthly program of sampling at selected stream sites determined that one area of mixed agricultural and undisturbed rangeland contributed significant amounts of total soluble inorganic nitrogen. Sediment phosphorus uptake and release rates were determined with aquatic three-phase microcosms. The results indicated that sediment phosphorus mass loadings were small (less than 5% of the total loading) compared to stream phosphorus mass loadings if the hypolimnion is aerobic. Anoxic conditions could cause sediment phosphorus releases to be greater than stream phosphorus mass loadings (about 68% of the total).

Descriptive limnologies indicated that the reservoir was alkaline (pH about 8.0 and alkalinities usually around 200 mg $CaCO_3/l$), dimictic, weakly stratified, and usually well oxygenated. Nutrient levels were usually highest during the winter and at greater depths. Highest total phosphorus and orthophosphate levels were generally within a range of 50-100 μg/l whereas total nitrogen and total soluble inorganic nitrogen concentrations ranged from 0.1 to 2.0 mg/l. Blue-green algae were the dominant algal type comprising 80 percent of the total algal composition. Algae were most numerous and chlorophyll *a* levels were the highest (greater than 10 μg/l) during the winter. The summer copper sulfate applications apparently kept summer algal biomass low (less than 5.0 μg/l).

Mt. Dell Reservoir's trophic state was determined with Carlson's (1977) trophic state indices, Vollenweider's (1976) phosphorus loading model, Palmer's (1969) algal genus pollution index, and the Lake Evaluation Index of Porcella et al. (1980). The reservoir is in a mesotrophic/eutrophic state. Possible restoration strategies were discussed in relation to the results and practical considerations. Copper sulfate application, selective withdrawal, aeration/circulation, in-lake phosphorus inactivation, and sediment removal appeared to be the more reasonable.

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INTRODUCTION

Nature of the Problem

Recent evidence of trihalomethane (THM) production in the drinking water supply systems of Salt Lake City and Ogden, Utah (Peters et al. 1981) led Salt Lake County and the Utah Water Research Laboratory (UWRL) to search out the THM precursor sources. Although THM precursors are thought to be mainly naturally occurring humic substances, algal cells and their metabolites are also possibilities (Hoehn et al. 1980, Bernhardt 1980). In fact, Peters et al. (1981) found the THM production in the Salt Lake City system to be associated with water from a reservoir with significant eutrophication and algal nuisance problems.

Mt. Dell Reservoir in Salt Lake County, Utah, is the drinking water storage reservoir with a history of summer algal blooms (Lee 1980). The Salt Lake County and UWRL studies have been directed towards defining the eutrophication process in Mt. Dell Reservoir and recommending viable restoration strategies. These strategies would reduce algal related problems requiring treatment (filtration costs, taste, odor, etc.) and could also reduce potential THM precursors.

Research Objectives

Effective lake restoration strategies are formulated from information quantifying the degree of eutrophication. Quantification of eutrophication in Mt. Dell Reservoir during 1980-1981 was the major purpose of this study. Specific objectives were to:

1) Determine the major nitrogen and phosphorus sources within the tributary watershed.

2) Quantify the nutrient concentrations in the reservoir sediments.

3) Determine phosphorus uptake and release rates of the sediments.

4) Describe the general limnology of the reservoir.

5) Quantify the major forms of nitrogen and phosphorus in the reservoir.

6) Determine the limiting nutrients in water from Mt. Dell Reservoir, Parley's Creek, and Dell Creek.

7) Determine and assess the trophic state of Mt. Dell Reservoir.

EUTROPHICATION AND TROPHIC STATE INDICES

Types of Indices

Eutrophication can be defined as nutrient and organic matter enrichment of a lake ecosystem that results in high biological productivity and reduces the lake volume (Likens 1972). The nutrient and organic matter inputs are largely carried into the lake by runoff from the tributary watershed. Such factors as the hydrodynamics of lake circulation, uptake and release of nutrients by the sediments, nutrient dynamics and the forces constraining dynamic interactions, and morphometry determine the specific manifestations of eutrophication in a given lake. These manifestations, largely considered undesirable, include algae, macrophytes, oxygen depletion, and sedimentation.

Many inputs, factors, and manifestations of eutrophication can be used as trophic state indices. These indices measure the degree and type of eutrophication and thereby guide the selection of lake restoration procedures.

The trophic state of a lentic system may be qualitatively classified as oligotrophic, mesotrophic, or eutrophic. The numerous methods that can be used to determine trophic status include coarse resolution approaches (univariate and multivariate techniques and nutrient budgets) and high resolution simulation models (USEPA 1979a). Complex ecosystem models (Russell 1975; Jorgensen 1979; Scavia and Robertson 1980) predict events more accurately than coarse empirical approaches but are more complex than necessary for formulating management strategies (Tapp 1976). They are perhaps better used to characterize ecosystem structure and function and were thus not pursued further for the purposes of this study. Coarse resolution techniques are simple to use and require a relatively small data set.

Univariate Methods

Univariate methods assess trophic status with one parameter. The National Eutrophication Survey (USEPA 1974) tried four commonly measured parameters (Table 1). Other parameters such as total kjeldahl nitrogen (Leuschow et al. 1970; Williams et al. 1978), specific conductance (Beeton 1965), and phytoplankton concentration (Taylor et al. 1979) have also been used.

Carlson (1977) developed a trophic state index (TSI) which uses a scale of 0 to 100 instead of the three traditional descriptors (oligotrophic, mesotrophic, and eutrophic). An increase of 10 units indicates a doubling in algal biomass. The index assumes that Secchi depth is a power function of chlorophyll concentration and hence algal biomass. Total phosphorus has long been known to be related to chlorophyll (Sakamoto 1966; Dillon and Rigler 1974a; Jones and Bachmann 1976; Smith and Shapiro 1981), and Carlson incorporates this relationship into a TSI. Three separate TSI values can be obtained by measuring Secchi depth (SD), chlorophyll concentration (Chl), and surface total phosphorus (TP). The equations are

$$\mathrm{TSI(SD)} = 10 \quad 6 - \frac{\ln \mathrm{SD}}{\ln 2}$$

>50 = eutrophy
41-50 = mesotrophy
<41 = oligotrophy . . . . (1)

Table 1. NES criteria for trophic status of lakes (USEPA 1974).

Parameter	Oligotrophy	Mesotrophy	Eutrophy
Total Phosphorus ($\mu g/l$)	$\leq$ 10	10-20	$\geq$ 20
Chlorophyll *a* ($\mu g/l$)	$\leq$ 4	4-10	$\geq$ 10
Secchi Depth (meters)	$\geq$ 3.7	2.0-3.7	$\leq$ 2.0
Hypolimnetic Dissolved Oxygen (% saturation)	$\geq$ 80	10-80	$\leq$ 10

$$\mathrm{TSI(Chl)} = 10 \left(6 - \frac{2.04 - 0.68 \ln \mathrm{Chl}}{\ln 2}\right)$$

>55 = eutrophy
50-55 = mesotrophy
<50 = oligotrophy . . . . (2)

$$\mathrm{TSI(TP)} = 10 \quad 6 - \frac{\ln \frac{48}{\mathrm{TP}}}{\ln 2}$$

>47 = eutrophy
37-47 = mesotrophy
<37 = oligotrophy . . . . (3)

where all parameters represent summer means or medians and units of SD are in meters and Chl and TP in mg/m^3. Carlson's indices are currently receiving criticism (Lorenzen 1980; Megard et al. 1980; Edmondson 1980; Walker 1980) aimed at the inability of the Secchi transparency index to account for abiotic influences on Secchi transparency. Therefore, the use of Carlson's indices may be limited to systems with low color and turbidity.

One other parameter used in univariate estimation of the trophic state is dissolved oxygen (DO). Porcella et al. (1980) listed several approaches based on DO data, and these included calculating deficits or deficit rates and measuring hypolimnetic, water column, and transformed minimum DO concentrations. Many of these may not adequately reflect lake productivity. Indices based on hypolimnetic DO concentrations have the disadvantage of assuming that allochthonous inputs of organic matter are small relative to those produced in the lake (Wetzel and Likens 1979). This may not be true where the watershed area is much greater than the lake area.

Sediment oxygen demands also contribute to hypolimnetic oxygen deficits (Baker and Adams 1982). The relationship between the deficit and lake productivity, however, is complicated by the fact that sediment oxygen demand represents lake productivity over a period of time and a lag may exist between the time organic matter was produced and the time it was decomposed. Thus, a change in lake productivity may not alter the hypolimnetic DO deficit until some later date.

Porcella et al. (1980) used an instantaneous total lake equilibrium DO calculation to describe lake quality with respect to physical processes and respiration/photosynthesis. The calculation is based on incremented absolute values of net differences with depth between observed oxygen content and the saturation value of the water at its observed temperature and atmospheric pressure. Relationships have been derived between oxygen deficits and temperature (Lasenby 1975), lake morphometry (Charlton 1980), and phosphorus loading (Welch and Perkins 1979; Cornett and Rigler 1979).

Multivariate Methods

Multivariate indices incorporate more than one parameter into a trophic index. The most common multi-parameter trophic index is species diversity. The greater the number of taxa and the more equal their proportions, the greater the diversity (Pielou 1966). Although some researchers believe diversity can be related to water quality (Wilhm and Dorris 1968; Wetzel 1975), Green (1979) cited numerous reports where the authors disagreed.

Other indices are based on indicator organisms (Nygaard 1949; Palmer 1969; Taylor et al. 1979). Trophic state is inferred from the dominance of particular species. These indices, although useful, require an extensive knowledge of taxonomy and are probably not applicable for routine analysis.

Shannon and Brezonik (1972) have constructed a trophic state index (TSI) based on the seven variables of primary production, chlorophyll a, total phosphorus, total organic nitrogen, Secchi depth, specific conductivity, and Pearsall's cation ratio. They obtained good agreement with nitrogen and phosphorus loading and the TSI for a number of lakes in Florida. This technique requires measurements of a large number of parameters, including some which are not commonly measured (such as Pearsall's cation ratio). Also, Reckhow (1979) points out that the index was derived with data from Florida lakes and does not recommend it for the north temperate region.

One multivariate technique which could be applicable to Mt. Dell Reservoir is the Lake Evaluation Index (LEI) developed by Porcella et al. (1980, 1981). The LEI uses summer (June through August) means of Secchi depth (SD), total phosphorus (TP), total nitrogen (TN), chlorophyll a (CA), dissolved oxygen (DO), and macrophytes (MAC). The LEI model is similar to Carlson's index in that a numerical scale from 0 to 100 is used instead of the qualitative descriptors. The contributions of the six parameters are:

$$XSD = 60 - 14.426 \ln (SD) \quad (SD \text{ in meters}) \quad \ldots \quad (4)$$

$$XTP = 4.15 + 14.427 \ln (TP) \quad (TP \text{ in mg/m}^3) \quad \ldots \quad (5)$$

$$XTN = 14.427 \ln (TN) - 23.8 \quad (TN \text{ in mg/m}^3) \quad \ldots \quad (6)$$

$$XCA = 30.6 - 9.81 \ln (CA) \quad (CA \text{ in mg/m}^3) \quad \ldots \quad (7)$$

$$XDO = 10 \text{ (net DO)} \quad (DO \text{ in mg/m}^3) \quad \ldots \quad (8)$$

$$XMAC = PMAC \quad (PMAC \text{ as \%}) \quad \ldots \quad (9)$$

where PMAC is the percent macrophyte coverage of lake area subject to macrophytic growth. The LEI value is obtained with the equation:

$$LEI = 0.20\ (XSD + XTP + XCA + XDO + XMAC) \quad \ldots \quad (10)$$

where XTN replaces XTP if it is smaller.

Nutrient Budgets

Nutrient budgets can also be used to assess trophic state. The approach evolved from the work of Vollenweider

(1968) who established a relationship between nutrient loading and trophic response. Later, Vollenweider (1969) incorporated his relationship into a simple mass balance model such that the change in phosphorus mass per unit time equals the phosphorus input mass minus the phosphorus output mass minus the phosphorus mass lost to the sediments.

Dillon (1974) reviewed Vollenweider's model and criticized several aspects. Numerous revised derivations of the loading-response relationship followed (Dillon and Rigler 1974b; Lerman 1974; Imboden 1974; Dillon 1975; Kirchner and Dillon 1975; Chapra 1975; Vollenweider 1975; Larsen and Mercier 1976; Snodgrass and O'Melia 1975; Vollenweider 1976; Reckhow 1979; Benndorf 1979; Reckhow et al. 1980). Nevertheless, Vollenweider's model remains a useful predictive tool. Baker and Adams (1982) tested the predictive reliability of Vollenweider's (1976) model on lakes and reservoirs in the intermountain region and concluded that it was useful as a management tool as long as the model's basic assumptions were met. Mueller (1982) reached the same conclusions from a separate study but indicated that the Dillon-Rigler (1974b) model had slightly better predictive capabilities. In general, most authors use levels of 10 and 20 µg/l of ambient lake total phosphorus for upper oligotrophy and lower eutrophy, respectively.

THE STUDY SITE

Site Location

Mt. Dell Reservoir (Figure 1) is located on Parleys Creek, a tributary of the Jordan River, approximately 14.5 kilometers east of Salt Lake City, Utah (40°45' N: 111°43' W) at an altitude of 1676 meters above sea level.

Historical Aspects

Mt. Dell Reservoir was established in 1917 when Parleys Creek was impounded with a multiple arch dam. The dam was 36.6 meters high and held approximately 1.14 million m^3 of water. Later, the dam was raised to increase the storage capacity to 4.33 million m^3. The storage capacity has since been decreased to 3.95 million m^3 by silt accumulation.

Few studies of the water quality in Mt. Dell Reservoir exist. Black and Veatch (1950) investigated the water quality in the streams supplying water to Salt Lake City but did not study the reservoir. Ivory (1967) studied various algal populations and attempted to correlate these to in-lake physical parameters and external nitrogen and phosphorus loading. Anderson and Key (1973) studied nitrogen and phosphorus concentrations at selected sites within the watershed in an attempt to locate possible nutrient sources.

Copper sulfate has been applied to Mt. Dell Reservoir (Table 2) for a number of years to control algae blooms. These applications are still occurring although the total yearly amount applied has lessened. It is not known when these applications began, but records are available dating back to the 1950s.

Reservoir Characteristics

Mt. Dell Reservoir rests on calcareous shale bedrock and the surrounding area contains a mixture of limestones, alluvial and colluvial deposits (Utah Geological and Mineralogical Survey 1964). The vegetation surrounding the reservoir is characteristic of chapparal and sagebrush zones (Cronquist et al. 1972). Dominant species are _Artemesia tridentata_ Nutt.; _Quercus gambelii_ Nutt.; _Acer grandentatum_ Nutt.; and _Agropyron_ species.

Highway I-80 parallels the east side of the reservoir. Two sludge ponds are located on the east side near the convergence of the reservoir arms. These ponds are utilized during the back-flushing process in the treatment plant, and excess water drains back into the reservoir.

Reservoir releases are through a multi-level outlet works discharging to Parleys water treatment plant. The lake is dimictic and exhibits weak summer stratification in the main basin. Morphological characteristics are given in Table 3.

Reservoir storage is generally at a maximum after spring runoff and gradually diminishes to supply Salt Lake City's water demands during the summer. The volume often drops to 20 percent of the maximum by mid-winter and then increases during spring runoff.

Watershed Characteristics

Two streams enter Mt. Dell Reservoir; Dell Creek on the north side and Parleys Creek on the east side (Figure

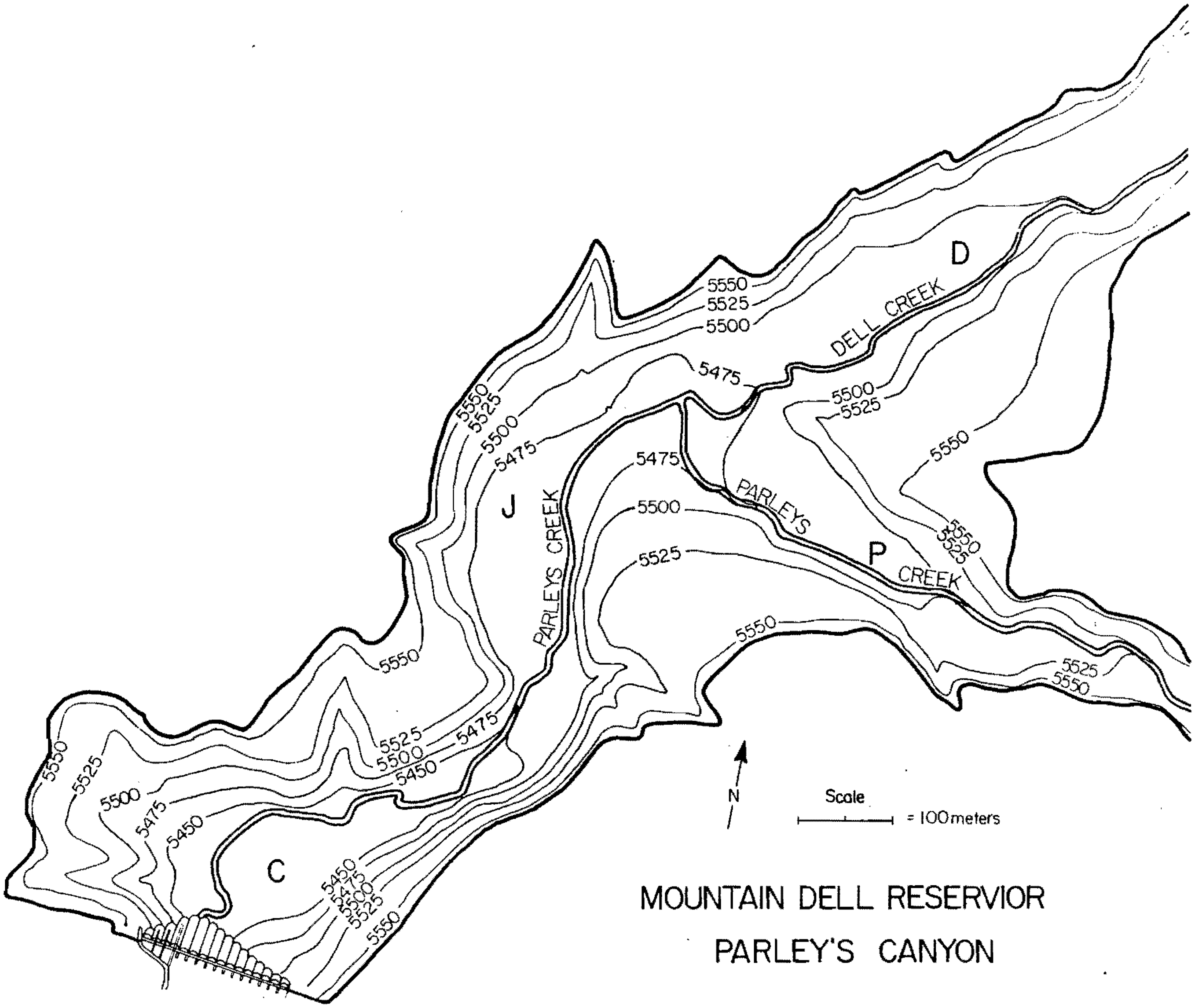

Figure 1. Mt. Dell Reservoir topography with water sampling sites (contours in feet).

2). Drainage areas and mean flows are given in Table 3. The Dell Creek watershed is primarily undisturbed rangeland. A large picnic area containing chemical toilets is present as well as numerous smaller picnic areas. Some river bottom land (0.1 km^2) is used for hay production. The Parleys Creek watershed is dominated by undisturbed rangeland on the west side and Highway I-80 on the east.

In 1961, a 0.4 km^2 golf course containing a club house and a small park was established next to Parleys Creek approximately 0.8 kilometers above the reservoir. Toilet wastes are trucked out of the watershed. Traditionally, a high nitrate fertilizer is applied each spring, and the greens are lightly fertilized with the same type of fertilizer each month during the summer (Anderson and Key 1973).

Table 2. Total and monthly kilograms of copper sulfate applied from 1970 to 1981.[a]

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Jan.	91											
Feb.	9				45							
Mar.	218		3765	68	272		680					363
Apr.	962	5117	3992	1792	885	181	1066	930		340	522	386
May	4500	9671	8106	4196	4309	590	1746	2585	680	4150	2313	726
Jun.	6246	8369	7997	5851	4563	2812	2767	3901	2404	4876	2903	1157
Jul.	7575	4209	7348	4581	5511	7099	2926	3062	5742	3130	2971	2608
Aug.	5334	5302	4853	3992	3152	3810	1588	2790	4218	1497	907	454
Sep.	2032	2717	3016	2404	794	2177	1542	2971	2540	544	227	726
Oct.	544	2046	1750	1973	1270	953	544	1066	1814			454
Nov.				45								
Dec.												
Total	27511	37431	40827	24902	20801	17623	12859	17305	17398	14537	9843	6874

[a] Data obtained from Parley's Water Treatment Plant, Salt Lake County, Utah.

Table 3. Morphological characteristics of Mt. Dell Reservoir and the major creeks in the watershed (partially taken from Ivory 1967).

Mt. Dell Reservoir	
Drainage basin	130.8 kilometers^2
Surface area (max.)	0.34 kilometers^2
Volume (max.)	3.95 x 10^6 meters^3
Depth (mean)	11.8 meters
Depth (max.)	30.5 meters
Mean retention time	0.16 years
Parleys Creek	
Drainage area	58.0 kilometers^2
Mean flow	0.314 meters^3/sec
Dell Creek	
Drainage area	48.2 kilometers^2
Mean flow	0.337 meters^3/sec
Lambs Creek (also included in Parleys Creek data above)	
Drainage area	24.6 kilometers^2
Mean flow	0.171 meters^3/sec

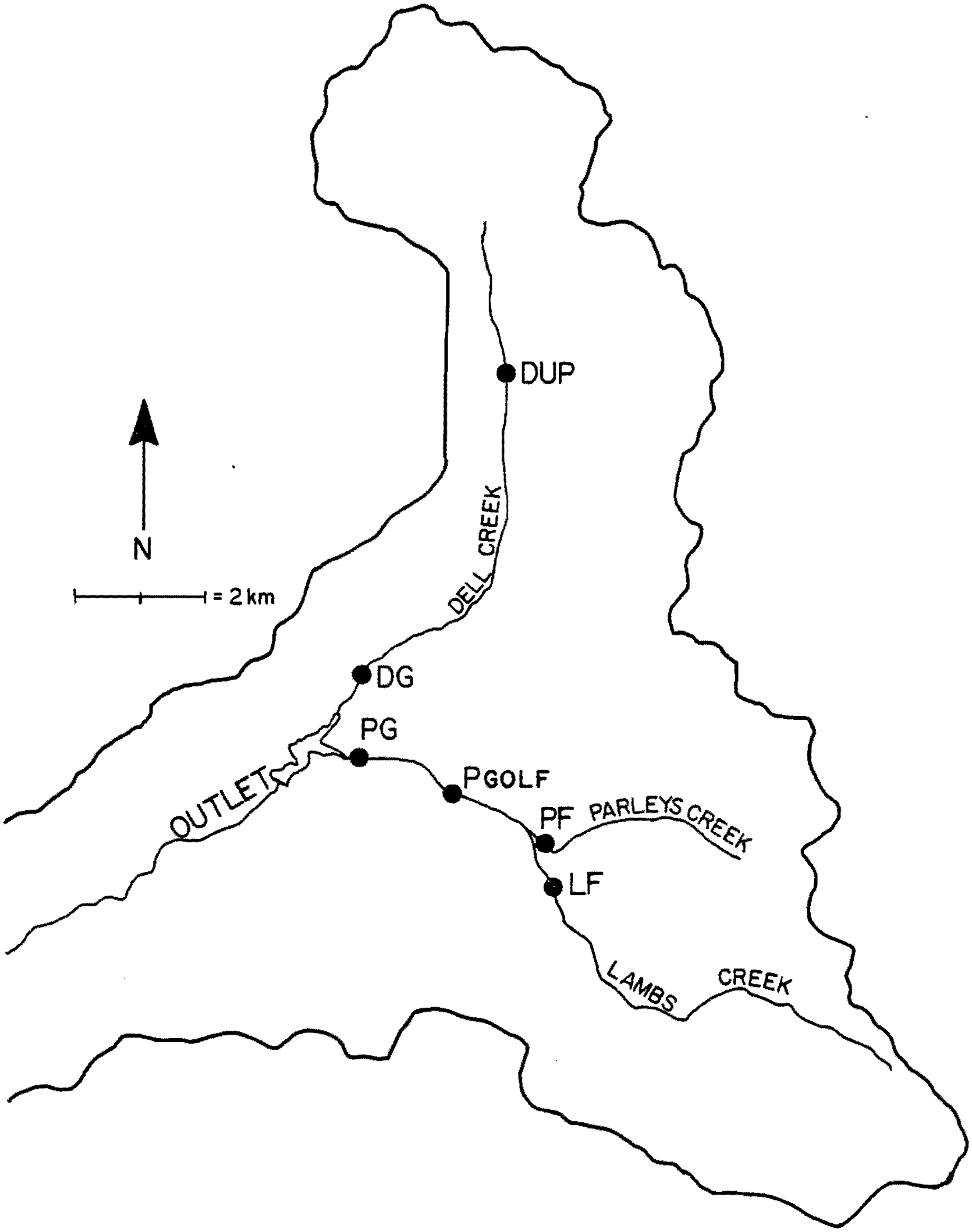

Figure 2. Watershed area and stream sampling sites.

Lambs Creek converges with Parleys Creek approximately 3.4 kilometers above the reservoir. The Lambs Creek watershed is mainly forested land containing coniferous species and aspen, but some exposed slopes contain chapparal and rangeland vegetation. About 30 summer homes, which utilize septic tanks, are located in this canyon.

Sampling Sites

Water and sediment sampling was undertaken on this project. Four water sampling sites (Figure 1) were chosen to represent general areas within the reservoir. These sites (C,J,P,D) were used for all water sampling in the reservoir. Sediment samples were taken from 17 different locations (Figure 3).

Stream sampling sites (Figure 2) were chosen to reflect differences in land use and for convenience of access. The land above DUP is undisturbed rangeland, and DG records the effects of the hay production operation. Sites PG and PGOLF delineated the golf course effect, and sites PF and LF were chosen to monitor the contributions from Lambs and Parleys Creeks before they converge.

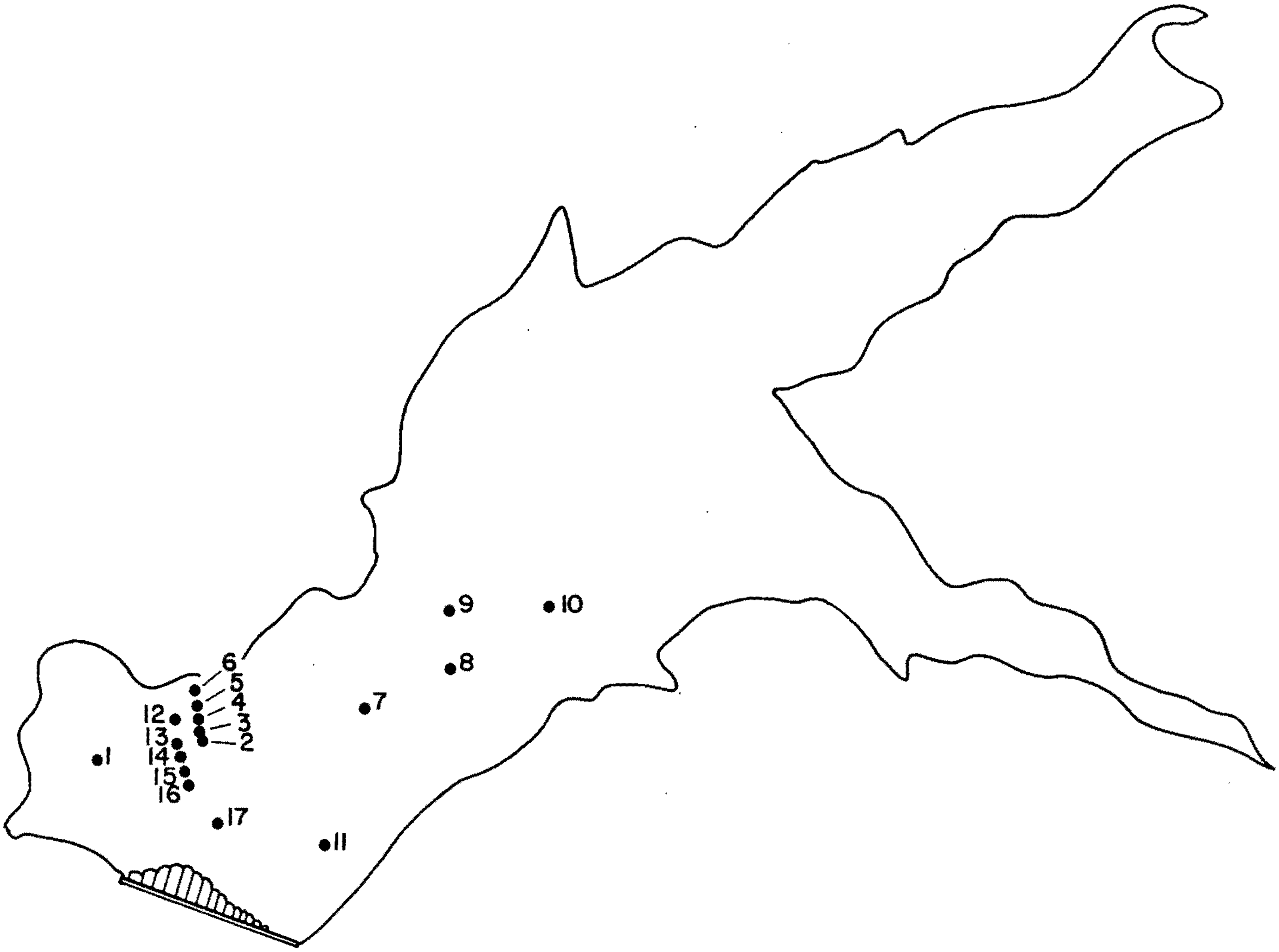

Figure 3. Mt. Dell Reservoir sediment sample sites.

SAMPLING AND INDEXING

Inflow

Six stream sampling stations were used to examine differences among land uses. Water from each station was sampled monthly at mid-channel and mid-depth for one year and analyzed for the parameters shown in Table 4. In addition, temperature and specific conductance measurements were taken with a YSI Model 33 conductivity meter. Water velocities were measured with a Marsh McBirney Model 201 current meter at surveyed points within a specified stream cross section. Water flows were calculated by multiplying the water velocity by the cross sectional area. Stations PG and DG contained weirs, and daily water flow values were obtained from Parleys water treatment plant.

Nutrient mass loading to the lake was estimated by multiplying the water flow times the nutrient concentration. Monthly nutrient mass loading values were based on the assumption that water flows and nutrient concentrations remained constant for each month. Monthly nutrient mass loadings for stations PG and DG were calculated by the product of integrated discharge vs. time plot and nutrient concentrations at the midpoint of the time interval (Scheider et al. 1979).

The nutrient mass loadings (total phosphorus, orthophosphate, and total inorganic nitrogen) were statistically analyzed with a Friedman Rank Sum Test (Hollander and Wolfe 1973). Because site PGOLF was not sampled each month, this site was not included in the statistical analyses. Instead, the monthly sum of the nutrient mass loadings from sites PF and LF was used.

Nutrient fluxes were also calculated to investigate differences among watershed subareas. Subareas within the watershed were delineated, characterized, and estimated (Table 5). Areal nutrient fluxes were calculated monthly by taking the difference in nutrient loading between adjacent sampling sites and dividing by the area contained within those sites.

Reservoir Sediments

Nutrient concentration status

The sediment sampling had two major purposes. An assessment of the differences in nutrient concentrations among sediments obtained from different locations might indicate localized point sources (Schmalz 1971). In addition, the measurements could be used to estimate the effect of reservoir drawdown on sediment nutrient concentrations.

Sediment samples were taken from 17 different locations in Mt. Dell Reservoir (Figure 3). Sediments from sites 1-11 were collected with a shovel during December 1980 when the drawdown had exposed these locations. Samples were taken from sites 13-17 with an Eckman dredge during December 1981. These sites have rarely been dewatered. Site 12 (also sampled December 1981) was located at approximately the same spot as site 4 and was sampled with a shovel.

Dried sediments were first sieved with a #120 USA Standard sieve and then analyzed for total nitrogen, total phosphorus, total organic carbon, and total available phosphorus (Table 4). Since replication was not performed, a hierarchical cluster analysis computer

Table 4. Methods and references for chemical and physical analyses.

Paramater	Method	Source
Dissolved oxygen	Azide modification of Winkler, Dissolved oxygen probe	APHA (p. 390, 1980)
Organic carbon[b]	Combustion, infrared	Menzel and Vaccaro (1964) Oceanographic International Carbon Analyzer
NITROGEN		
Ammonia	Indophenol	Solorzano (1969)
Nitrate-nitrite	Cadmium reduction	APHA (p. 376, 1980)
Kjeldahl nitrogen	Digestion, distillation	APHA (p. 383, 1980)
Total nitrogen	Micro-dumas Technique	Coleman total nitrogen analyzer manual model
Organic nitrogen	(Kjeldahl-N) - (NH_3-N)	
PHOSPHORUS		
Orthophosphate	Ascorbic acid	APHA (p. 420, 1980)
Total phosphorus	Ascorbic acid	APHA (p. 420, 1980)
Total phosphorus[a]	Persulfate digestion	Schmalz (1971)
Total available phosphorus[a]	Dilute Fluoride - dilute HCL soluble P	Schmalz (1971)
Total alkalinity	Potentiometric	APHA (p. 253, 1980)
Total and calcium hardness	EDTA titrimetric	APHA (p. 195, 1980)
Specific conductance	Conductivity probe	Mark V Water Quality Analyzer[c]
pH	pH probe	Mark V Water Quality Analyzer[c]
Temperature	Thermistor probe	Mark V Water Quality Analyzer[c]
Illumination	Photocell	Lambda LI-185 Meter[d]
Chlorophyll *a*	Fluorescence	APHA (p. 952, 1980)
Secchi disk transparency	Lee side of boat	Lind (1974)

[a] Sediment samples.
[b] Aqueous and sediment samples.
[c] Montedero Whitney Corp., San Luis Obispo, CA.
[d] LI-COR Inc/LI-Cor Ltd., Lincoln, NB.

Table 5. Description of watershed areas.

Area	Stream Section	Watershed Description Summary	Area (ha)
A	Source to DUP	Undisturbed rangeland and partially forested	3108
B	DUP to DG	Undisturbed rangeland and hay production	1710
C	Source to PF	Undisturbed rangeland, Highway I-80, and some beaver activity	2461
D	Source to LF	Undisturbed rangeland and summer homes	3341
E	PF/LF fork to PGOLF	Undisturbed rangeland, Highway I-80, and some beaver activity	1352
F	PGOLF to PG	Undisturbed rangeland, Highway I-80, and golf course	5128

program (Marshall and Romesberg 1979) was used to define similar locations with respect to the measured variables. This program used the average Euclidean distance as a measure of dissimilarity and an unweighted pair group method using arithmetic means as the clustering method (Sneath and Sokal 1973).

Nutrient uptake and release

Many lake restoration strategies use some form of sediment management (Dunst et al. 1974; USEPA 1979b; Jorgensen 1980; USEPA 1980). The design of these schemes requires quantification of sediment nutrient uptake and release.

The experimental unit. Three phase microcosms were used to assess eplimnetic and hypolimnetic sediments. The microcosms (Figure 4) were similar in design to those used by Porcella et al. (1975). These microcosms were filled with approximately 9 liters of water after sediment additions, and the

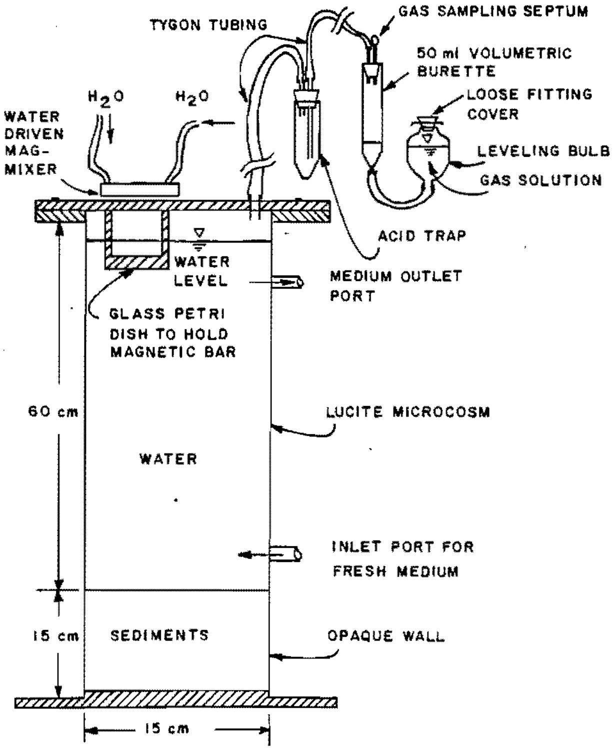

Figure 4. Schematic design of three phase aquatic microcosm.

water was mixed with magnetic driven water stirrers. The bottom 15 cm of the microcosms were painted black to inhibit growth of photosynthetic organisms in the sediments. Gases were retained by the addition of a gas trap containing 2.5 percent H_2SO_4 (Andrews et al. 1964), and an acid trap was added as a precautionary measure against acid entering the microcosms during medium exchanges.

<u>The experimental design</u>. The experimental design is outlined in Table 6. This design studied 12 experimental units under various light and dark conditions and with two sediment types. Thus, a 2 by 2 split plot factorial through time design was used to determine the effects of sediment type, light conditions, and time on a number of measured variables.

<u>The experimental conditions</u>. Light and temperature conditions were maintained as constant as possible for the study duration. Temperature was maintained at 20°C ± 2.5°C, and overhead lighting was provided by Optima 50 fluorescent bulbs (Duro Test Corporation). The lighted microcosms were placed under a 12 hour light-12 hour dark cycle. Light intensity reaching the sediment surfaces and water surfaces of the microcosms were 1450 and 5000 lux respectively.

<u>Sediment collection and analyses</u>. Sediments were collected from Mt. Dell Reservoir at two locations (sites 12 and 17) by previously discussed methods. Each sediment was thoroughly mixed the following day and analyzed (see previous subsection). Sediment subsamples were randomly added to each microcosm. The plan was to fill each microcosm with equal sediment weights and volumes, but gross density differences between the two sediment types (Table 7) prevented this. Sediments from site 12 weighed approximately 1.5-1.7 kilograms dry weight whereas those from site 17 weighed 0.9-1.1 kilograms. Sediment volumes from sites 12 and 17 were approximately 2.5 and 2.8 liters respectively. In the end, a compromise was reached where neither weight nor volume was equal.

<u>Input medium and exchange</u>. The input medium was intended to approximate average water conditions found in Mt. Dell Reservoir. Medium constituents and concentrations are given in Table 8. The medium was pretreated by first

Table 6. Microcosm experimental design.[a]

	Treatments			
Sediment:	Eplimnetic		Hypolimnetic	
Light:	Light/Dark	Dark	Light/Dark	Dark
Replicates:	EL1	ED1	HL1	HD1
	EL2	ED2	HL2	HD2
	EL3	ED3	HL3	HD3

[a]Chemical analyses on days 1, 7, 13, 18, ..., 54.

Table 7. Initial microcosm and sediment conditions.

Microcosm Replicate	Mass of Dry Sediment, g	Volume of Medium Added, ℓ
El1	1574	10.25
EL2	1599	10.14
EL3	1560	10.28
ED1	1578	10.27
ED2	1559	10.16
ED3	1617	10.23
HL1	1028	9.95
HL2	962	9.90
HL3	950	9.88
HD1	947	9.97
HD2	984	9.75
HD3	1050	9.83

Sediment Type and Replicates	Total P μg/g	Total N μg/g	Total Organic Carbon mg/g
E1	1156	422	6.85
E2	1172	495	6.79
E3	1168	298	7.52
H1	2010	2629	23.73
H2	2104	2372	23.26
H3	2092	2616	18.89

bubbling with carbon dioxide to dissolve calcium compounds and then aerating to increase the pH to normal levels. Initially, the aeration time was inadequate for lowering CO_2 levels in the medium, but the duration was later extended so that aeration effectively lowered CO_2 levels. The medium was then cooled to approximately 6 degrees below ambient water temperature to prevent mixing of fresh medium with that being removed. Medium exchange occurred every other day by following procedures outlined by Porcella et al. (1975). In order to keep approximately equal water retention times between microcosms with different sediment volumes, 950 ml were exchanged in microcosms with site 12 sediments whereas 900 ml were exchanged in microcosms with site 17 sediments. This resulted in a 20-day retention time for all microcosms.

Gas production. Gas production was monitored daily by reading the change in acid level on the 50 ml burettes. Room temperature and barometric pressure readings were also taken to account for any changes associated with these variables.

Chemical and gas analyses. Every 6 days the effluent water was retained and analyzed. Analyses included dissolved oxygen, total alkalinity, pH, total organic carbon, soluble copper, total phosphorus and orthophosphate, ammonia, nitrate-nitrite, total hardness, and calcium hardness (Table 4). In addi-

Table 8. Medium constituents and concentrations.

Stock Solution	Compound	Conc. in Stock g/l	Dilution in Feed	Element	Final Conc. in Microcosm (μg/l)
A_1	$NaNO_3$	0.607	1 → 1000	N	100
A_2	$MgSO_4 \cdot 7H_2O$	7.95	10 → 1000	Mg	1755
	$MgCl_2 \cdot 6H_2O$	9.47	10 → 1000		
A_3	$CaCl_2 \cdot 2H_2O$	0.642	100 → 1000	Ca	69600
	$Ca(OH)_2$	0.900	100 → 1000		
A_4	$NaHCO_3$	18.8	10 → 1000	Na	51500
A_5	$KHCO_3$	2.46	1 → 1000	K	1000
A_6	K_2HPO_4	0.790		P	14
A_7	$ZnCl_2$	0.017	1 → 1000	Zn	8
	$MnCl_2 \cdot 6H_2O$	0.250	1 → 1000	Mn	68
	H_3BO_3	0.550	1 → 1000	B	96
A_8	$CoCl_2 \cdot 6H_2O$	0.360	0.1 → 1000	Co	9
	$CuCl_2 \cdot 2H_2O$	0.110	0.1 → 1000	Cu	4
A_9	$FeCl_3 \cdot 6H_2O$	0.126	1 → 1000	Fe	26
	$Na_2EDTA \cdot 2H_2O$	0.300	1 → 1000	$Na_2EDTA \cdot 2H_2O$	

tion, gas samples were taken from the gas septa with 1-ml disposable syringes and analyzed for CO_2, O_2, and N_2 with a Hewlett Packard 5750 research gas chromatograph (refer to Porcella et al. (1975) for operating conditions).

Data analyses. The data collected were examined with a computer program that calculates mass balances for selected chemical species. This program also estimates concentration values for most variables on days between analyses. (See Porcella et al. (1975) for complete details of the program.) Output from the program was statistically analyzed by ANOVA methods (Hurst 1972).

General Limnology

The reservoir's general limnology was described with 14 different parameters. Measured physical parameters included temperature, Secchi disk transparency, and illumination, while chemical parameters included dissolved oxygen, specific conductance, pH, total and orthophosphate phosphorus, alkalinity, organic nitrogen, ammonia, nitrate, nitrite, and chlorophyll a (Table 4).

Four sites (C, J, P, D) were sampled monthly at different depths during this study. However, sites J, P, and D could not be sampled every month because the drawdown dewatered these sites periodically.

Mean concentrations of total phosphorus, orthophosphate, total nitrogen, total soluble inorganic nitrogen (nitrite + nitrate + ammonia), chlorophyll a, and uncorrected chlorophyll were analyzed statistically with ANOVA analyses to determine spatial differences. Because the drawdown dewatered sites J, P, and D for a number of months, only June through August data were statistically analyzed.

Nutrient Limitation

Since many existing trophic state indices assume a phosphorus limited system, it is prudent to determine a system's nutrient limitations before using these indices. Monthly water samples from the surface of Mt. Dell Reservoir (site C, Figure 1), site PG, and site DG were tested for nutrient limitation with the "Algal Assay Procedures: Bottle Test" (USEPA 1971, 1978). Samples were pretreated by filtering the water through a rinsed 0.45 μ millipore membrane filter. The pretreated waters were routinely analyzed for the major forms of nitrogen and phosphorus (Table 4), and inorganic soluble nitrogen:orthophosphate phosphorus ratios were determined.

Chemical ratios are based on a simple photosynthesis-respiration reaction and its stoichiometry and usually do not account for nutrient co-limitations. However, Chiaudani and Vighi (1974) and Forsberg (1980) proposed certain co-limitation ranges for TSIN:PO_4-P (5-10) and TN:TP (10-17) ratios respectively, and these are used in this study.

The bioassays were conducted according to USEPA (1971, 1978) procedures with *Selenastrum capricornutum* as the test alga. All experimental units were in triplicate. Table 9 lists the algal bioassay medium constituents and the basic experimental design. Disodium EDTA (ethylene dinitrilo tetraacetic acid) was added to the reservoir water during experimentation as a precautionary measure against metal toxicity.

Algal biomass was indirectly measured with optical density (Bausch and Lomb Spectrophotometer 70 at 750 nm, 1 cm cell) readings taken daily for 14 days. Optical density is linearly related to biomass as volatile suspended solids (Porcella et al. 1973). The regression equation used to convert optical density (OD) to volatile suspended solids (VSS) is:

$$\text{VSS, mg/l} = 280\ (\text{OD}) + 17.9 \quad . \quad . \quad (11)$$

The results of each treatment were reported as the maximum standing crop (MSC) obtained during the 14 days. MSC values were then statistically analyzed with a Duncan's Multiple Range Test (Steel and Torrie 1980; Nie et al. 1975) where differences were considered significant at the 95 percent level. Phosphorus limitation is indicated when treatment C obtains a significantly higher MSC than all other treatments except D. Nitrogen limitation is indicated when treatment B is significantly higher in MSC than all other treatments except D. Co-limitation is indicated when treatment D has significantly higher MSC values than all other treatments. In this study, co-limitation did not imply simultaneous limitation by nitrogen and phosphorus but rather to a state where one nutrient is exhausted almost as fast as the other.

Metal toxicity is present when treatment A+ is significantly higher in MSC than treatment A. Treatments with disodium EDTA additions were used to determine limiting nutrients of reservoir water. Nutrient limitations are indicated in the same manner as those treatments without disodium EDTA additions.

Table 9. Algal bioassay medium constituents and experimental design.

Treatment	Constituents
A	Control (sample water only)
A+	Control + 1.0 mg $Na_2EDTA\ 2H_2O/l$[a]
B	Control + 4.2 mg N/l as $NaNO_3$
B+	Control + 4.2 mg N/l as $NaNO_3$ + 1.0 mg $Na_2EDTA\ 2H_2O/l$[a]
C	Control + 0.093 mg P/l as K_2HPO_4
C+	Control + 0.093 mg P/l as K_2HPO_4 + 1.0 mg $Na_2EDTA\ 2H_2O$[a]
D	Control + N + P (as above)
D+	Control + N + P + $Na_2EDTA\ 2H_2O$ (as above)[a]

[a]Reservoir water only.

Trophic State Indices

For a better overall picture of the trophic state of Mt. Dell Reservoir, a number of indices were applied. From these, a relative trophic state range encompassed both optimistic and pessimistic estimates (Bradford and Maiero 1978). The trophic indices applied were Carlson's TSI indices, the LEI model, Vollenweider's (1976) loading model, and a qualitative assessment of indigenous algal groups and species.

Carlson's TSI equations and the LEI model were discussed in the literature review, and the required variables (TP, SD, Chl) and (TP, SD, CA, TN, DO, PMAC), respectively, were measured as described in a previous section. Carlson's TSI values were calculated monthly to provide an insight to seasonal fluctuations in the trophic state.

Vollenweider's model was used to predict epilimnetic chlorophyll a. Vollenweider's model equation is:

$$\text{Chl } \underline{a}\ (\text{mg/m}^3) = 0.367 \left(\frac{L_p/q_s}{(1 + \sqrt{\bar{z}/q_s})} \right)^{0.91} \quad \ldots\ldots\ (12)$$

in which

L_p = areal phosphorus loading ($mg/m^2/yr$)

q_s = areal water loading (m/yr)

$\bar{z}$ = mean depth (meters)

Monthly phosphorus loadings were calculated by multiplying each stream's monthly phosphorus concentration by the average water flow for that month. This study used 15 years of data to calculate an average monthly flow for each stream. The monthly phosphorus loading values were then added to give an average annual phosphorus loading. The average reservoir surface area was calculated by averaging 15 years of data obtained from the Salt Lake Water Department (SLWD). These data were in the form of water volumes but were converted to surface areas by use of depth-area curves. Phosphorus loading per unit area was calculated by dividing the annual phosphorus loading term by the average reservoir surface area.

The water loading per unit area was calculated by dividing the average inflow plus precipitation by the average reservoir surface area. Mean inflows and areas were calculated from 15 years of SLWD data while precipitation data were obtained from climatological records.

Since the 1980-1981 water year was moderately "dry," Vollenweider's (1976) model was also used with 1980-1981 hydrologic data to see if the predicted mean summer epilimnetic chlorophyll a concentration differed from that predicted with "average" water year data.

The short hydraulic retention time (0.16 year) of the reservoir and the fact that releases are timed to match water supply needs may cause great error in Vollenweider's model prediction. Vollenweider assumes that a calendar year is the time frame in which limnological processes occur. With such a short hydraulic retention time and the drawndown required to meet water supply needs, many hydrological parameters (such as reservoir volume, area, and retention time) can vary widely within a year's time. These changes and their effects may be lost when an annual time scale is used.

In order to examine the situation in a shorter time frame, total phosphorus areal and critical loadings (see Vollenweider 1976) were calculated monthly for both the 1980-1981 water year and the "average" water year. These calculations were intended to indicate not only when critical loadings occurred but also the effect of different hydrologic data on total phosphorus areal and critical loadings.

Finally, Palmer's (1969) algal pollution index was used to rate the reservoir water with respect to organic pollution. The presence of certain genera indicates the relative degree of organic pollution (Table 10). Genera present in concentrations of 50 per milliliter are noted and the pollution index values summed. A score of 20 or more indicates high organic pollution whereas scores of 15-19 indicate a possibility of high organic pollution. Lower scores suggest low organic pollution, unrepresentative samples, or some interfering substance. All reservoir water samples collected were analyzed for algal identification and enumeration.

Table 10. Palmer's algal genus pollution index.

Genus	Pollution Index
Anacyctis	1
Ankistrodesus	2
Chlamydomonas	4
Chlorella	3
Closterium	1
Cyclotella	1
Euglena	5
Gomphonema	1
Lepocinclis	1
Melosira	1
Micractinium	1
Navicula	3
Nitzschia	3
Oscillatoria	5
Pandorina	1
Phacus	2
Phormidium	1
Scenedesmus	4
Stigeoclonium	2
Synedra	2

RESULTS AND DISCUSSIONS

Physical and Nutrient Descriptions of the Watershed

Appendix A presents temperatures, flows, specific conductances, and nutrient concentrations for each stream site. Stream temperatures ranged seasonally from 0.0 to 13.0 degrees centigrade. The upper sites were generally one degree cooler than the lower sites.

Temperature corrected specific conductance ranged from 222 to 1538 µmhos/cm although most samples were between 300 and 600 µmhos/cm. Site PF was generally twice as high in specific conductance as the other sites. Low conductivities (222 and 427) at site PF during mid-winter were most likely due to dilution effects from ice melt. Conductivities generally remained in the 400-600 range during summer, fall, and winter but decreased by 100 µmhos/cm during spring runoff. In general, downstream sites had higher conductivities than upstream sites.

Stream nutrient loadings usually increased downstream (Table 11). Monthly loading of total phosphorus ranged from 0.32 to 125 kg/mo with the highest values during spring runoff and associated with the larger flow (see Appendix A). Orthophosphate loadings followed the same trends as total phosphorus but ranged from 0.13 to 33.7 kg/mo. Total soluble inorganic nitrogen (TSIN) loadings also peaked during spring runoff. TSIN loadings ranged from 0.88 to 231 kg/mo. Nutrient loadings generally increased ten fold during spring runoff.

Significant differences between sites were found for all nutrient loadings tested at the 5 percent level. Paired comparisons based on Friedman Rank Sums revealed only one possible major nutrient source and indicated that one watershed area may be eliminated from further study (Appendix A).

On the Dell Creek system, total phosphorus and orthophosphate loadings did not significantly differ between sites DG and DUP. However, there was a significant difference between total soluble inorganic nitrogen loadings.

The area between these two sites is mainly undisturbed rangeland but it does contain one hay field adjacent to the stream. Omernik (1976, 1977) reported rangeland as having lower inorganic nitrogen stream export values than other land uses whereas agricultural land had the highest values.

On the Parleys Creek system, the nutrient loadings of site PF differed significantly from the nutrient loadings at all other sites. Comparisons of nutrient loadings among the system's other sites did not indicate any significant differences.

Since the nutrient loadings of site PF were significantly lower than those of the combination site (LF + PF) and the nutrient loadings of site LF did not significantly differ from those of site LF + PF, it can be concluded that the upper branch containing site PF does not contribute significant amounts of nutrients to the main stream. Further study is needed to delineate major nutrient sources along the main stream.

Areal nutrient fluxes are presented in Table 12. Total phosphorus areal flux ranged from -24.7 to 26.2 gm/ha/mo

Table 11. Stream nutrient loadings (kg/month).

Site	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
								Total-P							
DUP	3.15	3.17	2.31	3.39	1.14	3.99	1.53	8.32	81.3	19.9	16.7	6.58			
DG	4.24	5.45	4.94	7.49	2.66	9.84	4.68	20.7	39.0	44.1	7.85	5.39	4.17	9.04	5.60
PF	b	0.88	0.76	0.88	0.73	0.53	0.32	6.48	42.8	14.2	1.65	2.42			
LF	6.25	7.49	6.81	3.67	2.58	10.3	2.75	12.8	71.9	44.5	17.5	16.6			
PGOLF	4.35	19.8	a	a	a	a	a	a	125	58.9	46.0	10.7			
PG	16.1	9.61	8.17	6.70	2.61	10.4	5.18	16.8	53.8	57.5	28.3	9.93	3.64	10.5	16.6
								Ortho-P							
DUP	2.42	2.76	1.98	1.94	1.14	0.79	1.53	3.57	27.1	17.6	10.7	4.21			
DG	2.94	4.73	1.53	7.28	4.20	4.22	4.46	7.93	16.6	33.7	5.87	4.23	4.17	9.04	4.20
PF	b	0.48	0.26	0.57	0.79	0.13	0.24	2.26	8.72	9.20	1.06	1.65			
LF	6.25	5.28	3.52	3.49	3.52	3.08	2.57	5.53	21.1	22.8	10.8	6.83			
PGOLF	4.35	7.16	a	a	a	a	a	a	24.0	31.0	21.0	6.99			
PG	12.3	7.44	3.79	7.19	3.29	2.11	4.11	6.11	13.9	22.1	10.7	9.91	2.60	6.78	8.61
								TSIN							
DUP	4.40	7.63	6.61	2.35	6.16	2.65	7.04	11.9	45.1	41.6	18.9	4.11			
DG	14.7	15.2	36.3	18.8	36.3	29.4	37.6	39.6	82.9	231	109	24.7	10.4	19.8	10.9
PF	b	2.42	2.35	0.88	7.27	2.65	1.32	9.25	6.46	25.1	4.63	9.91			
LF	16.9	74.9	7.05	18.4	51.7	49.3	18.4	51.1	70.5	152	72.2	36.0			
PGOLF	3.26	37.2	a	a	a	a	a	a	50.5	186	145	37.0			
PG	77.1	68.7	31.6	56.5	70.5	63.4	56.5	61.1	52.0	181	79.1	56.2	38.1	33.9	39.7

[a] Samples were not taken because the site was inaccessible.
[b] Sample site was selected in October.

Table 12. Areal nutrient flux (gm/ha/mo) of watershed areas.

Area	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
Total Phosphorus												
A	1.01	1.02	0.74	1.09	0.37	1.28	0.49	2.68	26.2	6.40	5.37	2.12
B	0.64	1.33	1.54	2.40	0.89	3.42	1.84	7.24	-24.7	14.2	-5.18	-0.70
C	a	0.26	0.23	0.26	0.22	0.16	0.10	1.94	12.8	4.25	0.49	0.72
D	2.54	3.04	2.77	1.49	1.05	4.19	1.12	5.20	29.2	18.1	7.11	6.75
E	a	8.45	a	a	a	a	a	a	7.62	0.15	19.9	-6.15
F	2.29	-1.99	a	a	a	a	a	a	-1.97	-0.27	-3.45	-0.15
Orthophosphate												
A	0.78	0.89	0.64	0.62	0.37	0.25	0.49	1.15	8.72	5.66	3.44	1.35
B	0.30	1.15	-0.26	3.12	1.79	2.01	1.71	2.55	-6.14	9.42	-2.82	0.01
C	a	0.14	0.08	0.17	0.24	0.04	0.07	0.68	2.61	2.75	0.32	0.49
D	2.54	2.15	1.43	1.42	1.43	1.25	1.04	2.25	8.57	9.26	4.39	2.78
E	a	1.04	a	a	a	a	a	a	-4.30	-0.74	6.76	-1.10
F	1.55	0.05	a	a	a	a	a	a	-1.97	-1.74	-2.01	0.57
TSIN												
A	1.42	2.45	2.13	0.76	1.98	0.85	2.27	3.83	14.5	13.4	6.08	1.32
B	6.02	4.43	17.4	9.62	17.6	15.6	17.9	16.2	22.1	111	52.7	12.0
C	a	0.72	0.70	0.26	2.18	0.79	0.40	2.77	1.93	7.51	1.39	2.97
D	6.87	30.4	2.86	7.48	21.0	20.0	7.48	20.8	28.6	61.8	29.3	14.6
E	a	-29.7	a	a	a	a	a	a	-19.6	6.58	50.4	-6.59
F	14.4	6.14	a	a	a	a	a	a	0.29	-0.98	-12.9	3.74

[a] Nutrient fluxes not calculated because site PF was not sampled.

with negative values usually occurring in late spring and summer. This phenomenon may be due to decreased turbulence and settling of particulate phosphorus at downstream areas or to algal uptake. The two watershed areas of Dell Creek, A and B, were comparable in areal total phosphorus flux during fall and winter, but were noticeably different during spring and summer. Area A doubled its monthly areal total phosphorus loading during late spring and summer, whereas watershed area B became a sink for total phosphorus. Watershed areas of Lambs and Parleys Creeks followed the same pattern of increased spring and summer areal loading and downstream areas acting as total phosphorus sinks. Orthophosphate areal flux generally exhibited the same trends as total phosphorus except area E acted as an orthophosphate sink during late spring and summer.

Total soluble inorganic nitrogen (TSIN) areal fluxes were variable with minimum and maximum values of -29.7 and 61.8 gm/ha/mo respectively. Watershed areas B and D had higher flux rates than other areas throughout the year. These patterns were also present in other nutrient fluxes but were less noticeable. TSIN flux rates were highest during runoff and areas E and F occasionally acted as TSIN sinks during the late spring and summer.

There is a possibility of taking advantage of the downstream areas which act as nutrient sinks. If algal uptake is an important factor, algal growth in these downstream sections could be promoted. Clearing of shaded stream sections could provide more sunlight reaching the stream and consequently enhance algal growth. Increased algal growth and biomass could temporarily reduce stream nutrient loading levels.

On the other hand, clearing shaded stream sections could affect stream biota. Thorup (1966) found that certain aquatic invertebrates inhabited shaded areas while others preferred open unshaded areas. Clearing shaded areas could drastically change the invertebrate community structure and possibly effect certain invertebrate predators (i.e., fish).

Clearing shaded areas may also alter the temperature regime (Karr and Schlosser 1977). Increased stream temperatures caused by clearing near-stream vegetation could lower in-stream oxygen concentrations, increase stream sediment nutrient release, and reduce invertebrate and fish production.

Reservoir Sediments

Nutrient concentration status of sediments

The results of the nutrient analyses for Mt. Dell Reservoir sediments are listed in Appendix B. These data indicated a general increase in TP, TN, and TOC concentrations with depth. Sites 1 and 10 contained relatively high concentrations of total available phosphorus, TP, TN, and TOC. These sites represented seep/spring areas. Horizontal differences were not apparent.

Cluster analyses for the four parameters (Figures 5 to 8) indicated similarities between locations with respect to TP, TN, and TOC when the two largest clusters in each figure are chosen. Seep/spring areas were grouped with those sites (14-17) which were rarely dewatered, whereas frequently dewatered sites tended to cluster into another group. Cluster analyses with total available phosphorus suggested no discernible grouping with respect to either vertical location or dewatering frequency.

These results may reflect drawdown effects. Kamp-Nielsen and Hargrave (1978) found accumulation of nitrogen, phosphorus, and organic carbon at the base of a steep slope in Lake Esrom. They suggested sediment slumping, turbidity flows, or gradual erosion

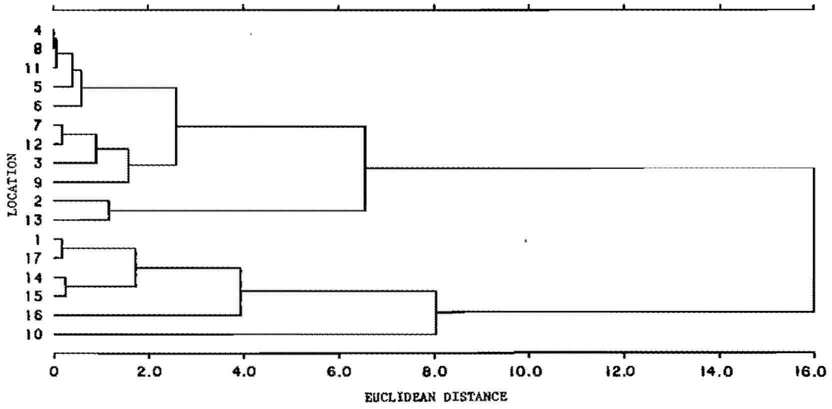

Figure 5. Dendogram of sediment total organic carbon.

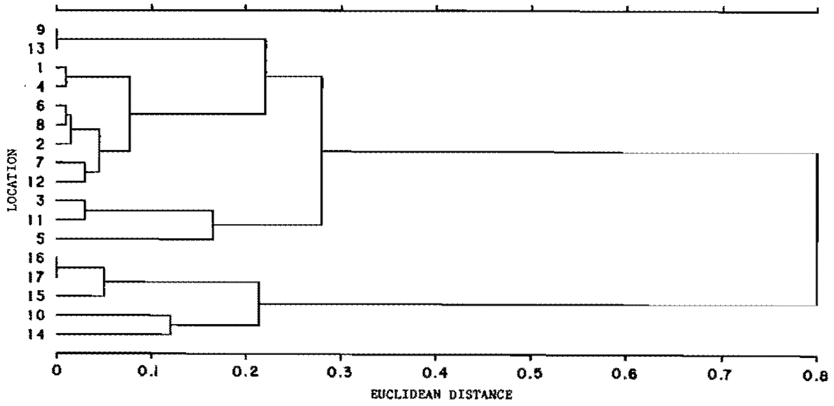

Figure 7. Dendogram of total available phosphorus.

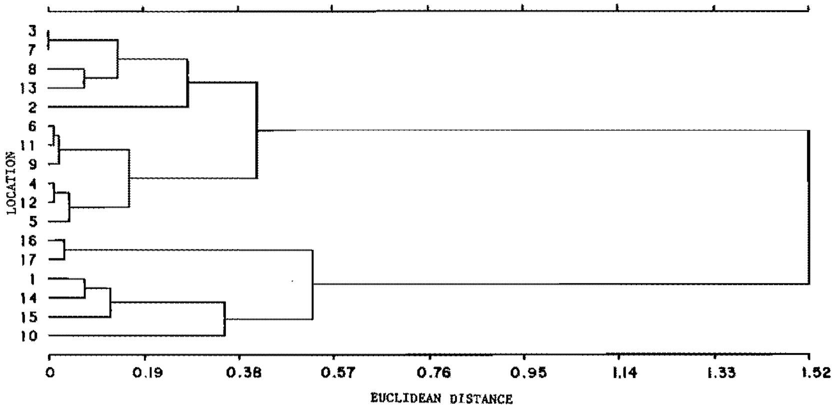

Figure 6. Dendogram of sediment total nitrogen.

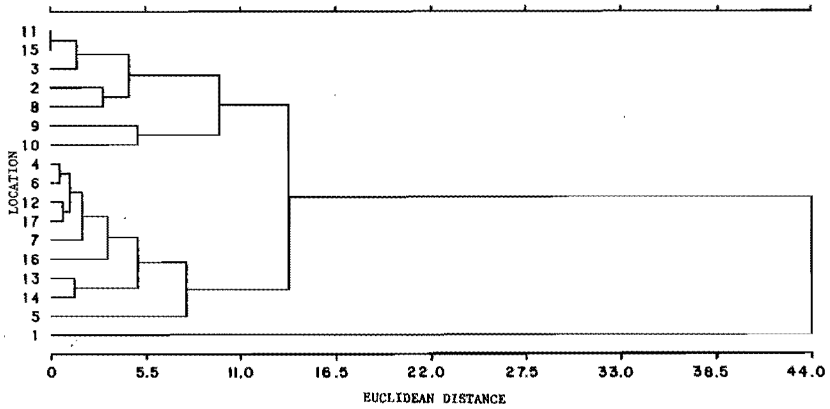

Figure 8. Dendogram of sediment total phosphorus.

could cause these accumulations. These effects would tend to move finer and lighter particles into deeper areas (Peterson 1981). Schmalz (1971) found this phenomenon in Hyrum Reservoir, Utah. The annual winter drawdown of Mt. Dell Reservoir could be causing a progressive drawdown movement of fine sediment particles to lower elevations.

Unfortunately, nutrient concentration analyses do not necessarily reflect the effects of a drawdown on sediment nutrient uptake and release. Conflicting reports are found in the literature, and it is probable that the effects are case specific. Fox et al. (1977) reported the same or lower nutrient levels in overlying water after a pool simulated drawdown, but Plotkin (1979) and Arenas and De La Lanza (1981) reported opposite results. Phosphorus concentrations in overlying waters were increased by simulated drawdowns. Gahler (1969) found increases in the soluble phosphorus fraction of sediment samples after freezing. These studies suggest the need for case specific research when determining the effect of a drawdown on sediment nutrient uptake and release.

Sediment nutrient uptake and release

Differences in nutrient uptake and release with substrate type (rarely dewatered or frequently dewatered), light, and time were assessed with three-phase microcosms. Table 13 lists the F values which were significant at the 1 or 5 percent level for 14 different parameters. These data can be found in the Utah Water Research Laboratory Library archives.

The most sensitive parameters to the treatments were the nitrogenous compounds. This would be expected since oxygen concentrations were initially low (<5.0 mg/l) but later increased, and these increases apparently led to nitrification of ammonia to nitrite and nitrate in the lighted microcosms containing hypolimnetic sediments. Total phosphorus concentrations did not significantly differ with any treatment except time, while orthophosphate concentrations were more sensitive. Significant interactions between time and substrate and time and light occurred. Total phosphorus mass balances were not significantly different in any treatment or interaction, while orthophosphate mass balances were significantly different for most treatments and interactions. These responses may reflect bacterial and oligochaete activities in the hypolimnetic sediment microcosms or algal PO_4-P uptake in the lighted microcosms. Dissolved oxygen concentrations were relatively sensitive to the treatments and responded to time, light, substrate and time, and substrate and light. All other parameters were low or moderate in sensitivity.

The lack of significant differences between total phosphorus concentrations or mass balances between the two sediment types (rarely dewatered and frequently dewatered) implies no significant effects of drawdown on sediment function. However, orthophosphate mass balances varied significantly with sediment type. Neglecting the lighted microcosm results, where algal uptake removed orthophosphate, epilimnetic (frequently dewatered) sediments released orthophosphate, whereas hypolimnetic (rarely dewatered) sediments usually acted as orthophosphate sinks. Dunst et al. (1974) reported one case where the authors suggested sediment desiccation will accelerate microbial conversion of organic forms of nutrients to inorganic forms. On the other hand, the results could simply reflect the sorptive capacities of the sediments (Williams et al. 1970).

Total phosphorus areal fluxes fror the sediments are presented in Figures 9 to 13 and Table 14. Positive values indicate net releases of total phosphorus from the sediments, whereas negative values represent sediment sinks for total phosphorus. Attached algae

Table 13. Significant effects and interactions on response parameters as affected by experimental treatments.

Response Parameters	Substrate Type (1)	Light Conditions (1)	Substrate x Light (1)	Time (26)	Substrate x Time (26)	Light x Time (26)	Substrate x Light x Time (26)
Total Phosphorus				1			
Orthophosphate				1	1	1	
Ammonia-N	5	1	5	1	5	1	5
Nitrate-N	1			5	1	1	
Nitrite-N	5	5	5	1	1	1	1
Total Organic Carbon	5	5					
Dissolved Oxygen		5	5	5	1		
pH					1		
Total Alkalinity				1			
Total Hardness		5		1			
Calcium				1		1	1
Magnesium		5		1			
Total Phosphorus Mass Balance							
Orthophosphate Mass Balance	1	1	1	1	1	1	

*1,5 percent significance levels (degrees of freedom).

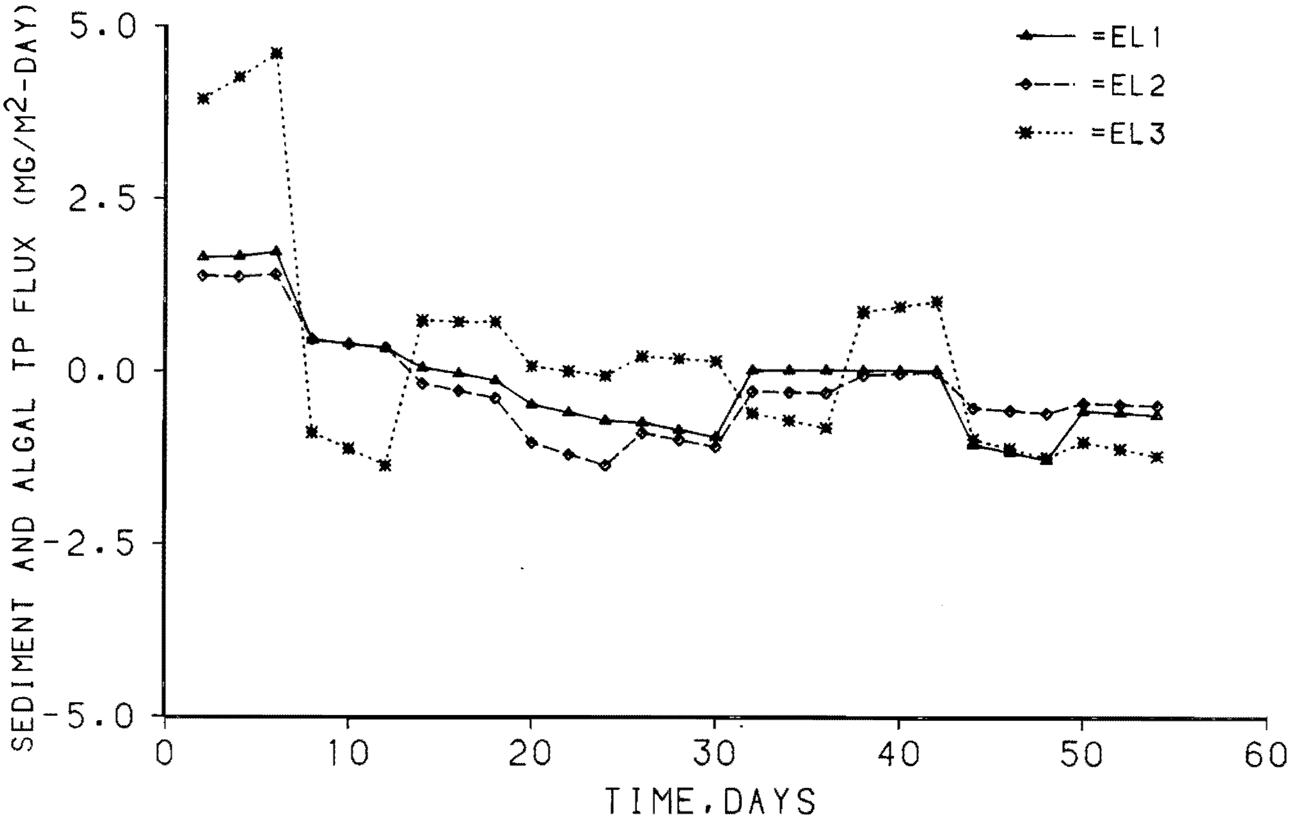

Figure 9. Sediment and algal total phosphorus flux for microcosms EL1, EL2, and EL3.

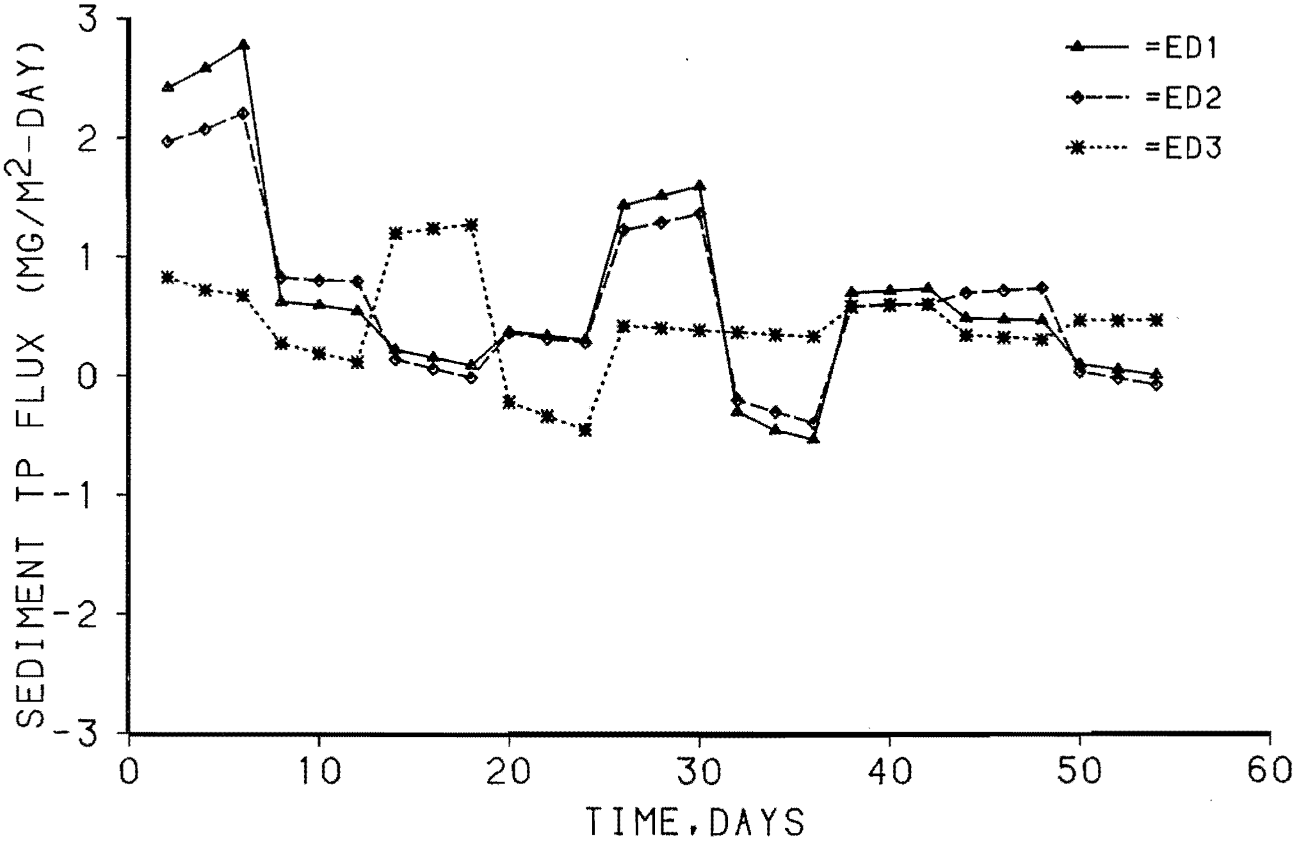

Figure 10. Sediment total phosphorus flux for microcosms ED1, ED2, and ED3.

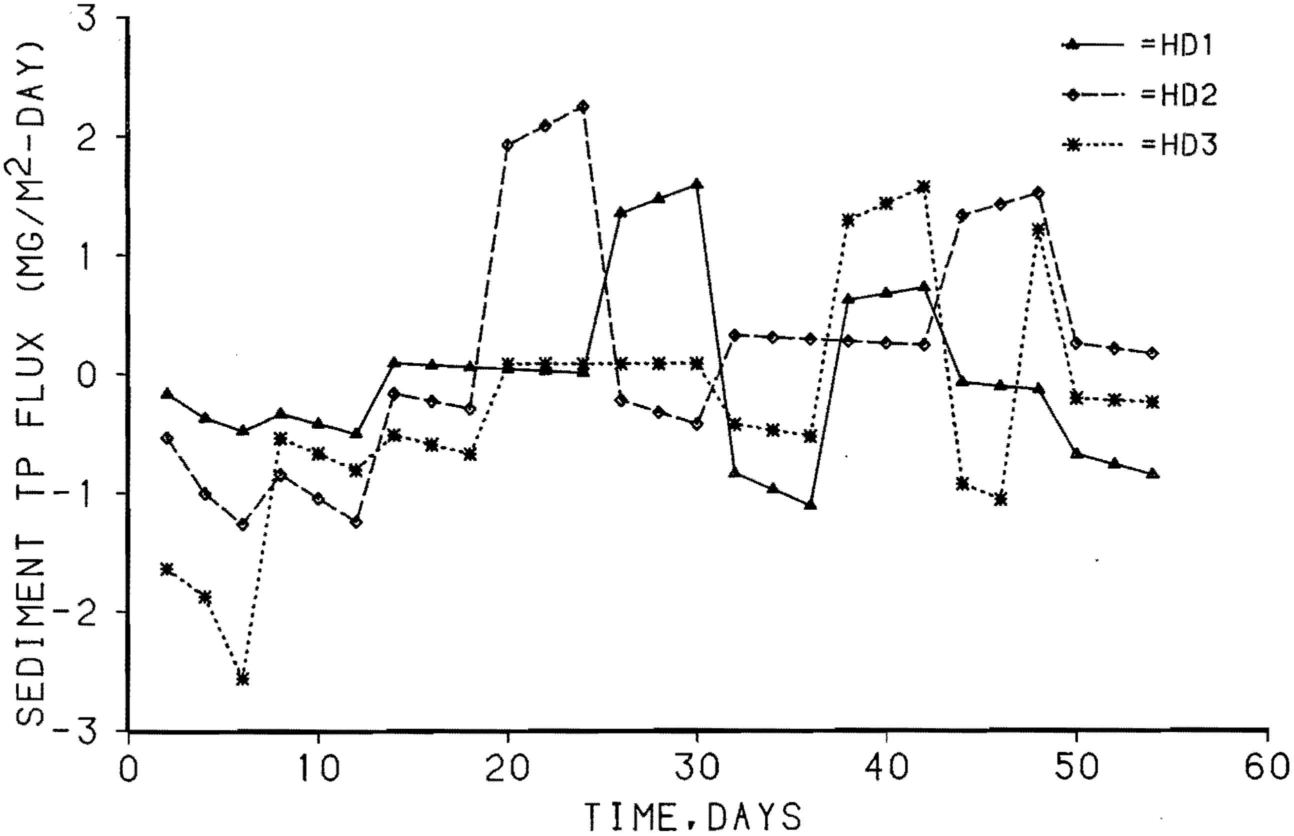

Figure 11. Sediment total phosphorus flux for microcosms HD1, HD2, and HD3.

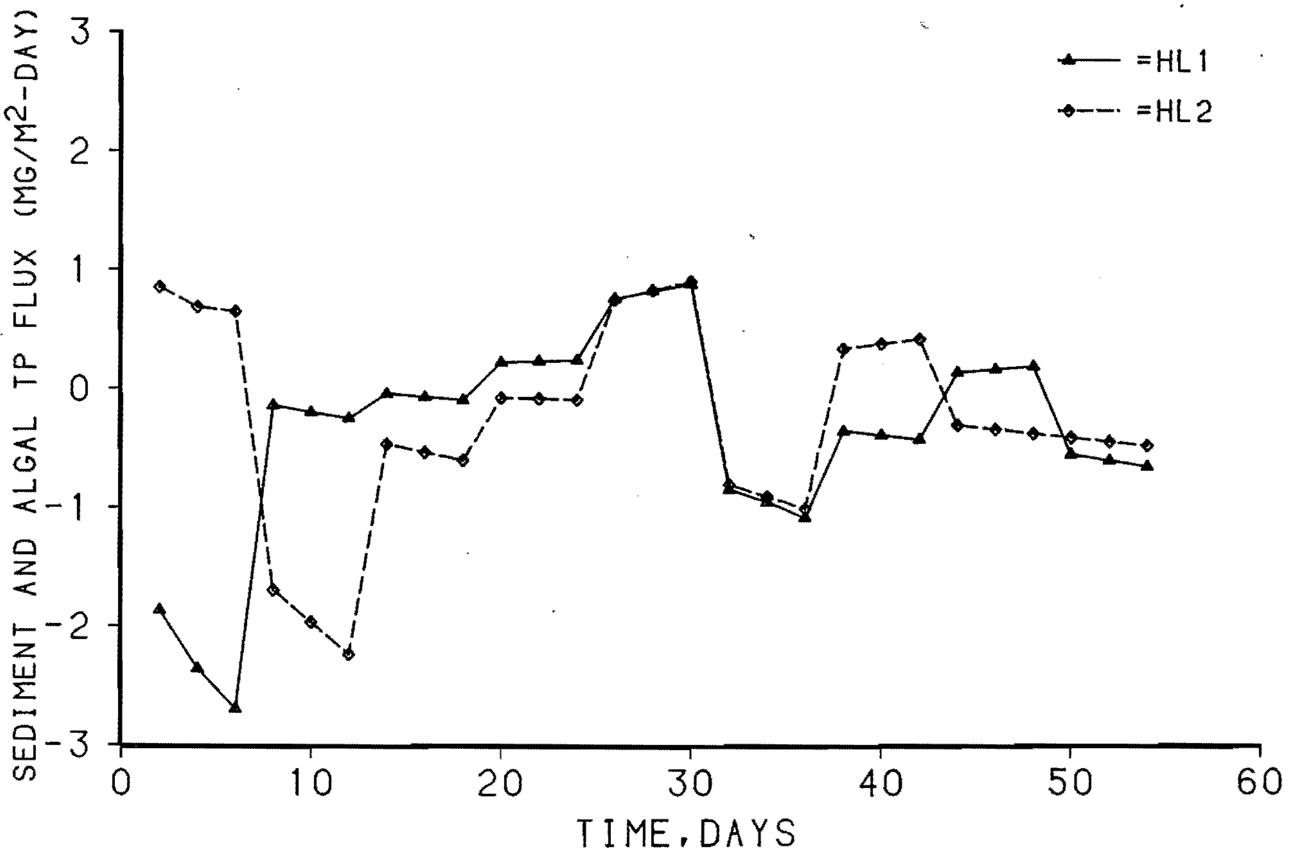

Figure 12. Sediment and algal total phosphorus flux for microcosms HL1 and HL2.

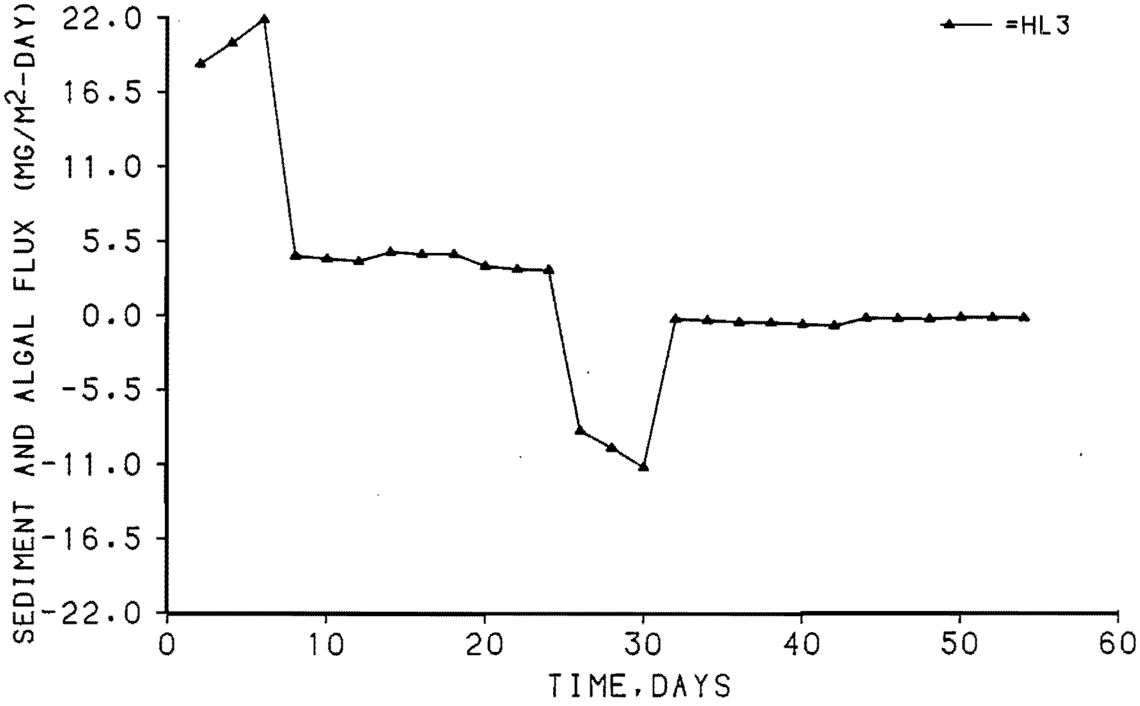

Figure 13. Sediment and algal total phosphorus flux for microcosm HL3.

Table 14. Ranges and means of total phosphorus flux rates (mg/m^2-day) for all microcosms.

Microcosm	Range	Mean
ED1	-0.538 to +2.773	+0.660
ED2	-0.400 to +2.204	+0.611
ED3	-0.457 to +1.263	+0.434
HD1	-1.212 to +1.579	-0.049
HD2	-1.266 to +2.241	+0.186
HD3	-2.566 to +1.555	-0.303
EL1	-1.294 to +1.720	-0.141
EL2	-1.371 to +1.398	-0.242
EL3	-1.371 to +4.597	+0.221
HL1	-2.696 to +0.866	-0.376
HL2	-2.239 to +0.849	-0.268
HL3	-11.28 to +21.84	+2.301

were not included in the mass balances of lighted microcosms; thus, the total phosphorus fluxes were essentially exchanges between a combination of sediments and attached algae and a combination of water and free floating algae. The dark microcosms did not contain algae, and bacteria were assumed to be minimal. Thus, total phosphorus fluxes were calculated on a basis of exchange between the sediments and the overlying water.

Total phosphorus flux rates were variable in all situations and did not reach a discernible steady state except in microcosm HL3 (see Figures 9 to 13). Epilimnetic sediments initially exhibited high positive flux rates, 1.0 to 5.0 mg/m^2-day, but the flux decreased below 2.0 mg/m^2-day after the first 10 days. Epilimnetic sediments and attached algae in illuminated microcosms (EL) acted as total phosphorus sinks, whereas eplimnetic sediments in continual darkness (ED) released total phosphorus. Hypolimnetic sediments in darkness (HD) were more variable through time than the ED or EL microcosms. HD sediment fluxes ranged from -1.21 to +2.24 mg/m^2-day. HD sediments initially acted as total phosphorus sinks (settling of particles from initial filling) but later released total phosphorus at rates up to 2.24 mg/m^2-day. The total phosphorus flux rates of the first two illuminated microcosms containing hypolimnetic sediments (HL) ranged from -2.70 to +0.87 mg/m^2-day and were usually negative. Microcosm HL3 flux rates were radically different than the other two replicates. Total phosphorus fluxes ranged from -11.3 to 21.8 mg/m^2-day. The initial total phosphorus releases coincided with low oxygen conditions (0.0 to 1.0 mg/l) while the temporary total phosphorus losses to the sediments and attached algae coincided with increased visible attached algae (see Appendix F) and higher dissolved oxygen concentrations. The steady state total phosphorus flux rate was approximately 0.42 mg/m^2-day.

Lee (1970) reviewed the factors which affect the transfer of materials between water and sediments. Dissolved oxygen concentration, sediment nutrient composition, pH, mixing, iron dynamics, and temperature are the most frequently studied factors (Mortimer 1941-1942; Syers et al. 1973; Banoub 1977; Lijklema 1977; Lee et al. 1977; Armstrong 1979; Frevert 1980; Holdren and Armstrong 1980). The phosphorus flux rates of microcosm HL3 did seem to reflect an effect of dissolved oxygen concentration, and in general, anaerobic conditions tend to enhance phosphorus releases from sediments. Water temperatures and pH were relatively constant. Iron was not analyzed. Because of mixing in this study, the results may overestimate in-lake release rates of unmixed situations.

The total phosphorus flux rates obtained in this study were comparable to other microcosm studies. Porcella et al. (1970) reported sediment total phosphorus release rates of 9.40 to 47.47 mg P/m^2-day. Medine (1979) reported steady state release rates of -0.678 to +0.095 mg P/m^2-day. The dark microcosms of this study exhibited total phosphorus release rates of -2.57 to +2.77 mg P/m^2-day.

The more reliable flux rates obtained in this study were from dark microcosms. This was so because algal uptake could not be quantified in the lighted microcosms. Since the experiment was run at room temperature (∿21°C), the resultant flux rates are probably higher than would normally occur in the reservoir. Holdren and Armstrong (1980) have shown increased nutrient release with increased temperatures. With this in mind, the experimental results are perhaps more applicable to summer conditions.

Total summer (June-August) external total phosphorus load was approximately 248 kilograms. Using the mean flux rate of total phosphorus from the dark microcosms, the sediment would contribute a phosphorus load of about 6.79 kilograms. This would only be 2.7 percent of the summer external phosphorus load. In general, Mt. Dell Reservoir sediments do not contribute a significant portion of the phosphorus load during the summer.

To provide an annual perspective, an ED+HD total phosphorus flux rate (Table 14) was used to estimate the mean annual total phosphorus mass loading to Mt. Dell Reservoir. This mass loading was 2.3 percent of the total annual total phosphorus loading to Mt. Dell Reservoir. To get an idea of what could happen during extreme conditions, a theoretical maximum annual total phosphorus mass loading was calculated from the highest total phosphorus flux rate obtained in the study (21.8 mg/m^2-day in HL3, anaerobic conditions). Using this flux rate, the sediments could contribute 66.8 percent of the total phosphorus mass loading. Therefore, the sediments could be a major phosphorus source if anaerobic conditions occur.

General Limnology

The general limnology is summarized in Table 15 and plotted for a number of parameters in Figures 14 to 28. The raw physical and chemical data can be found in Appendix D. Statistical analyses for detecting nutrient concentration differences between sampling sites can be found in Appendix E. Algal enumerations are presented in Appendix F.

Temperature data (Figure 14) indicated a dimictic lake with spring and fall isothermal conditions and winter and summer stratifications. Summer stratification began in May and ended in August with maximum surface temperatures reaching 21°C in July. The weak stratification patterns during summer were probably due to upper level port discharges which raise the thermocline or prevent thermal increases.

Dissolved oxygen concentrations (Figure 15) indicated hypolimnetic oxygen depletion in the main basin during July and August with minimum concentrations reaching 3.0-4.0 mg/l. Relatively higher concentrations were present during the summer at depths of 6 to 9 meters below the surface. These values coincided with high chlorophyll a concentrations. Permanent anoxic conditions were not found in the main basin.

The pH values measured were never below 7.4 (Figure 16). Thus, this reservoir would be classified as an alkaline system. Values of pH ranged from 7.4 to 8.5 with lower values generally found at greater depths. Except during July, pH values did not coincide well with metalimnetic maxima. Seasonally, pH remained relatively stable. In general, horizontal differences in pH were not apparent.

Excluding the March shoreline grab sample, temperature corrected conductivity ranged from 416-752 μmhos/cm (Figure 17). Conductivity generally increased with depth except during June (site J) and July (site C). Seasonal trends were indicated with generally higher conductivities during fall and winter (550-650 μmhos/cm) and low conductivities during May and June (400-500 μmhos/cm). High values during fall and winter might be due to low flow-high conductivity stream water inputs and relatively low reservoir volumes while low May and June values could have been due to spring runoff dilution effects with low conductivity stream waters.

Total alkalinity ranged from 104 to 263 mg $CaCO_3$/l. Total alkalinity profiles (Figure 18) were generally similar to conductivity profiles with higher values found at lower depths. High alkalinities (200-260 mg $CaCO_3$/l) were found during the winter and low values (100-200 mg/l as $CaCO_3$) during spring and summer. Low spring values were probably due to runoff dilution effects.

Table 15. Percent surface illumination at site C and Secchi transparencies.

Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
				Ice Cover								
1	31.8	59.1	45.7	11.2	16.7	2.0		18.2	54.3	54.5	51.4	66.7
2	20.5	34.1	18.9	11.1	3.6	0.8		1.0	21.7	29.9	28.6	36.7
3	18.2	18.6	8.6	2.1	0.5	0.4		0.4	10.2	19.5	25.0	23.3
4	11.4	9.1	5.1	0.4	0.2	0.1		0.2	4.1	13.0	16.4	14.4
5	9.1	5.0	2.6	0.3	0.1			0.1	1.2	7.8	10.7	8.9
6	3.6	2.7	1.1	0.2					0.8	4.5	6.4	6.7
7	2.3	1.8	0.2	0.1					0.3	2.6	3.6	3.3
8	1.5	0.1							0.2	1.3	2.5	2.0
9	0.9								0.1	0.3	1.4	1.2
10	0.7									0.1	0.7	0.9
11	0.5										0.4	0.4
12	0.3										0.1	0.1
13	0.1											
Bottom (m)	22.0	15.5	13.8	13.5	10.0	10.0		21.0	22.0	28.5	27.0	23.0
					Secchi Transparency (m)							
Site												
C	3.0	2.5	2.0	1.9	0.8	1.0		1.8	2.1	3.6	3.0	2.5
J		2.5	1.5						2.1	3.6	2.9	2.5
P		1.5[a]							2.5	3.7	2.0	2.5
D		1.7[a]							2.1	3.6	3.0	2.5

[a] On bottom.

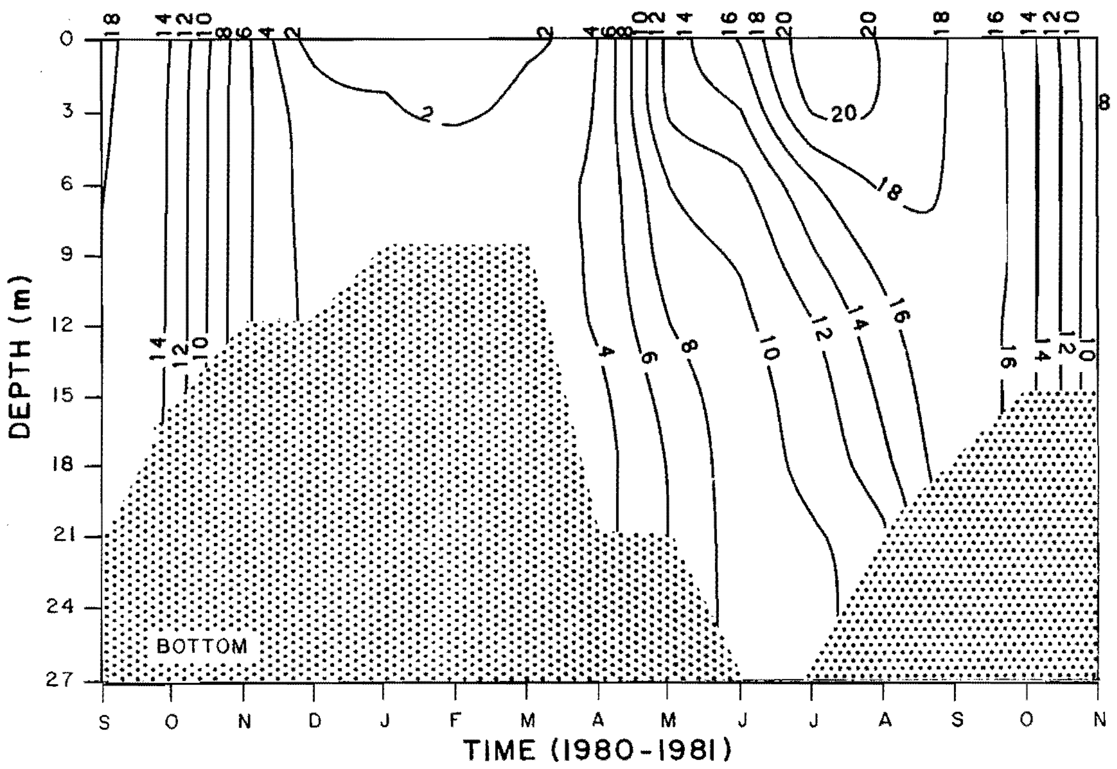

Figure 14. Temperature (°C) isopleth for site C in Mt. Dell Reservoir.

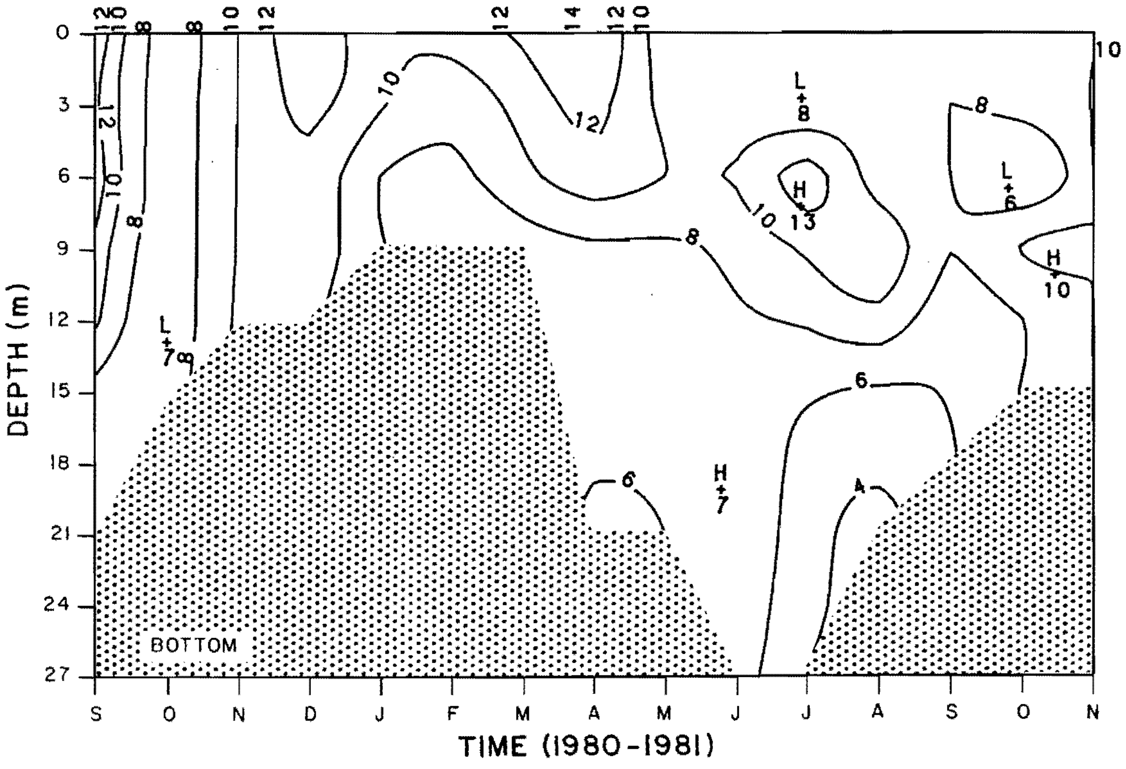

Figure 15. Dissolved oxygen concentration (mg/l) isopleth for site C in Mt. Dell Reservoir.

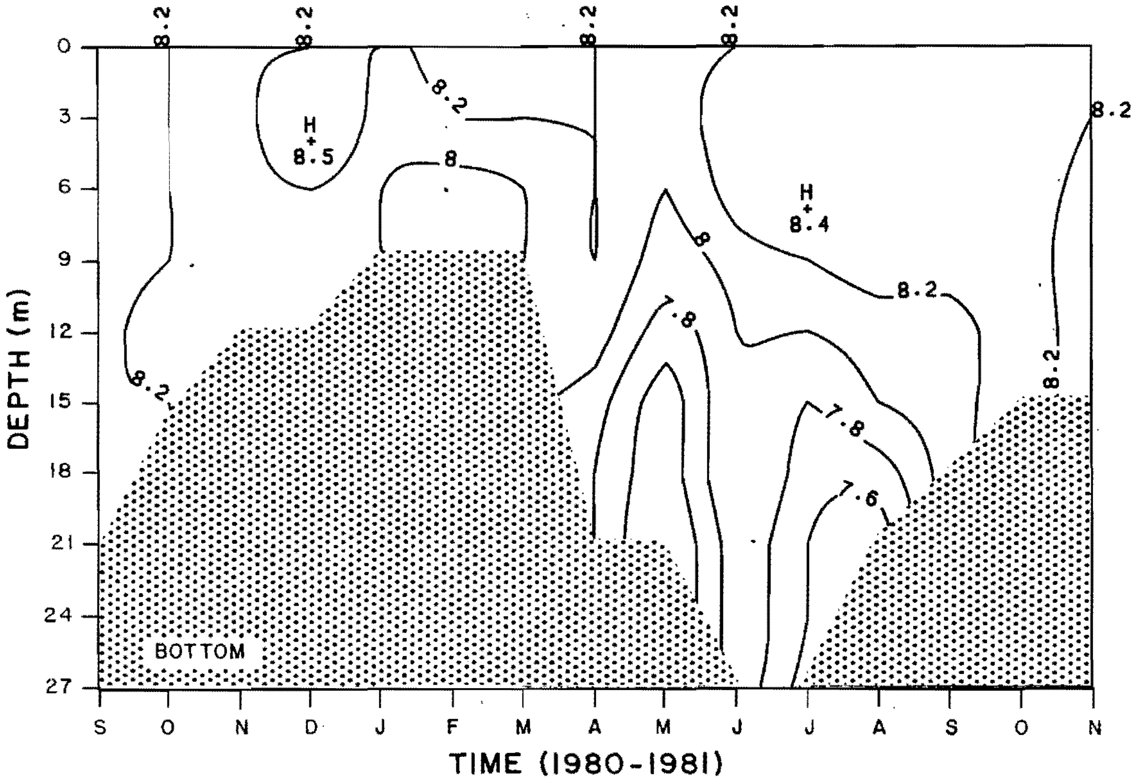

Figure 16. Isopleth of pH for site C in Mt. Dell Reservoir.

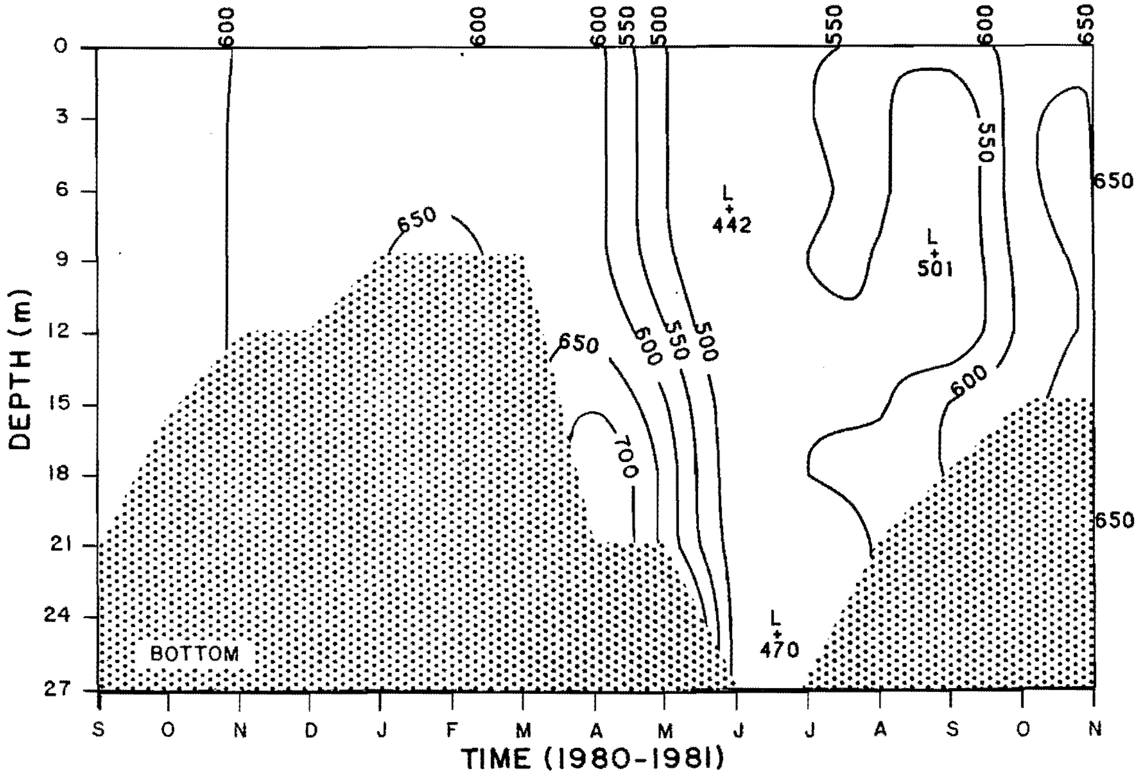

Figure 17. Specific conductance (μmhos/cm, corrected to 25°C) isopleth for site C in Mt. Dell Reservoir.

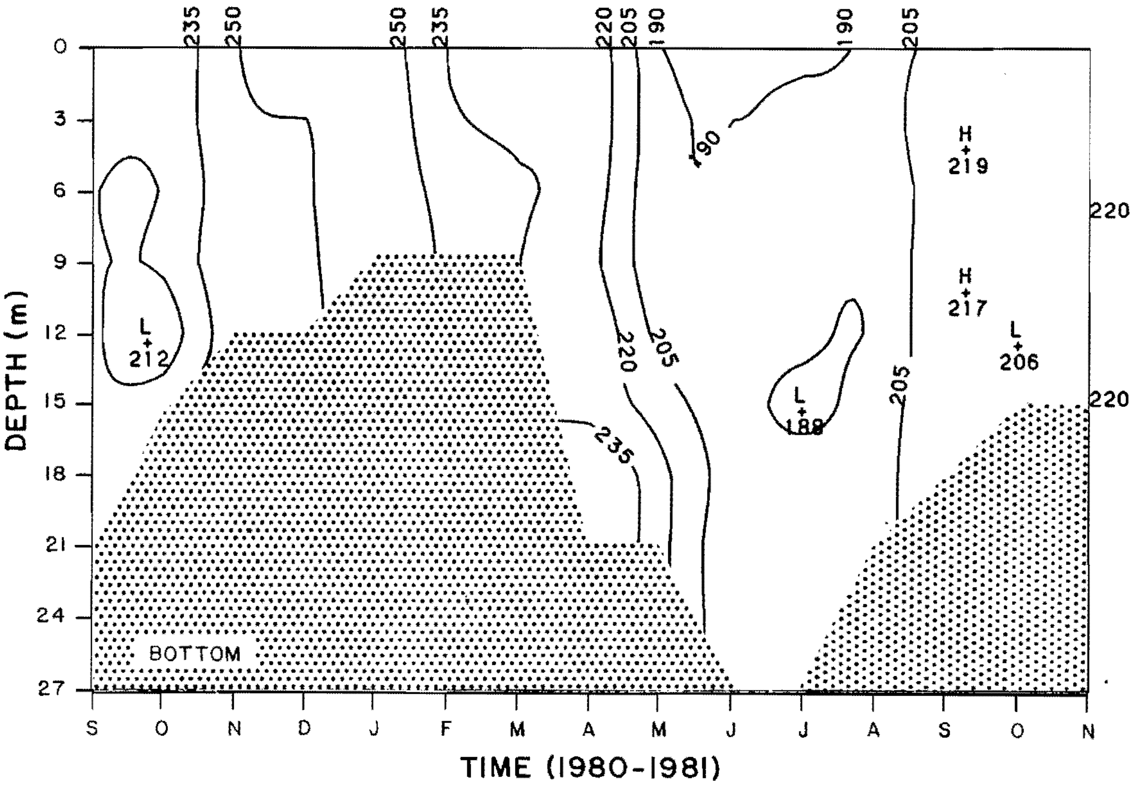

Figure 18. Total alkalinity (mg/l as $CaCO_3$) isopleth for site C in Mt. Dell Reservoir.

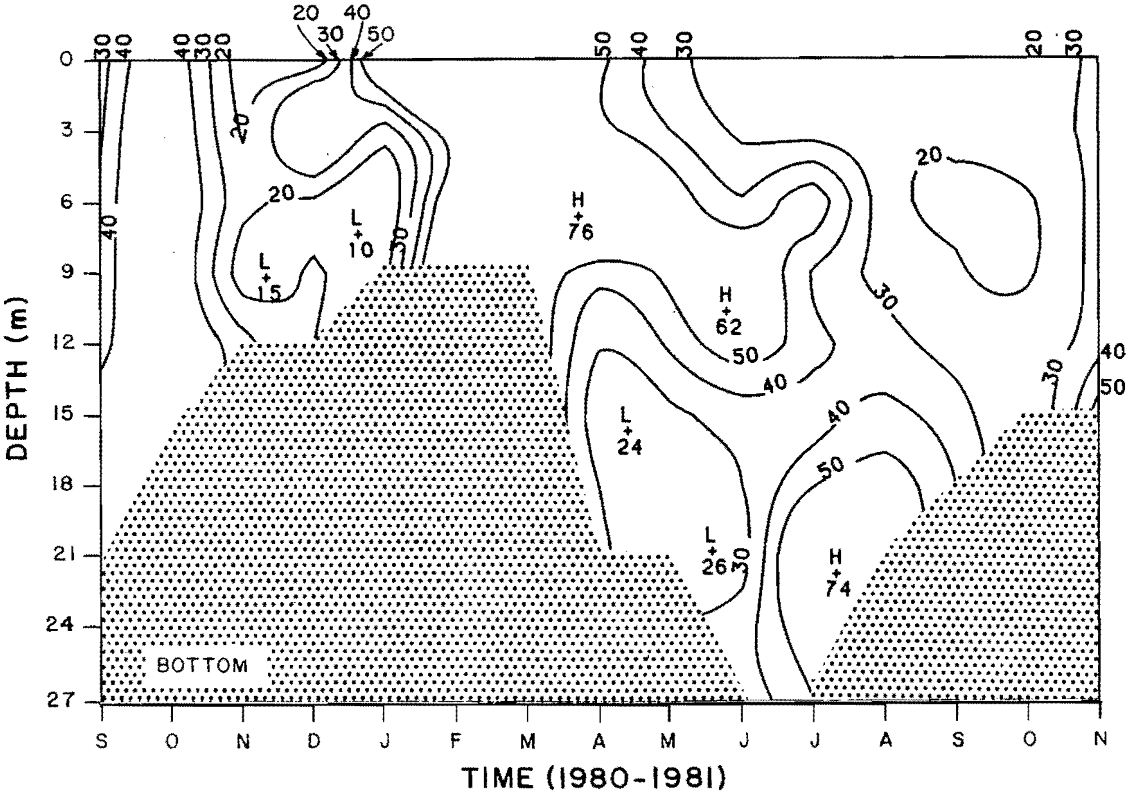

Figure 19. Total phosphorus concentration (μg P/l) isopleth for site C in Mt. Dell Reservoir.

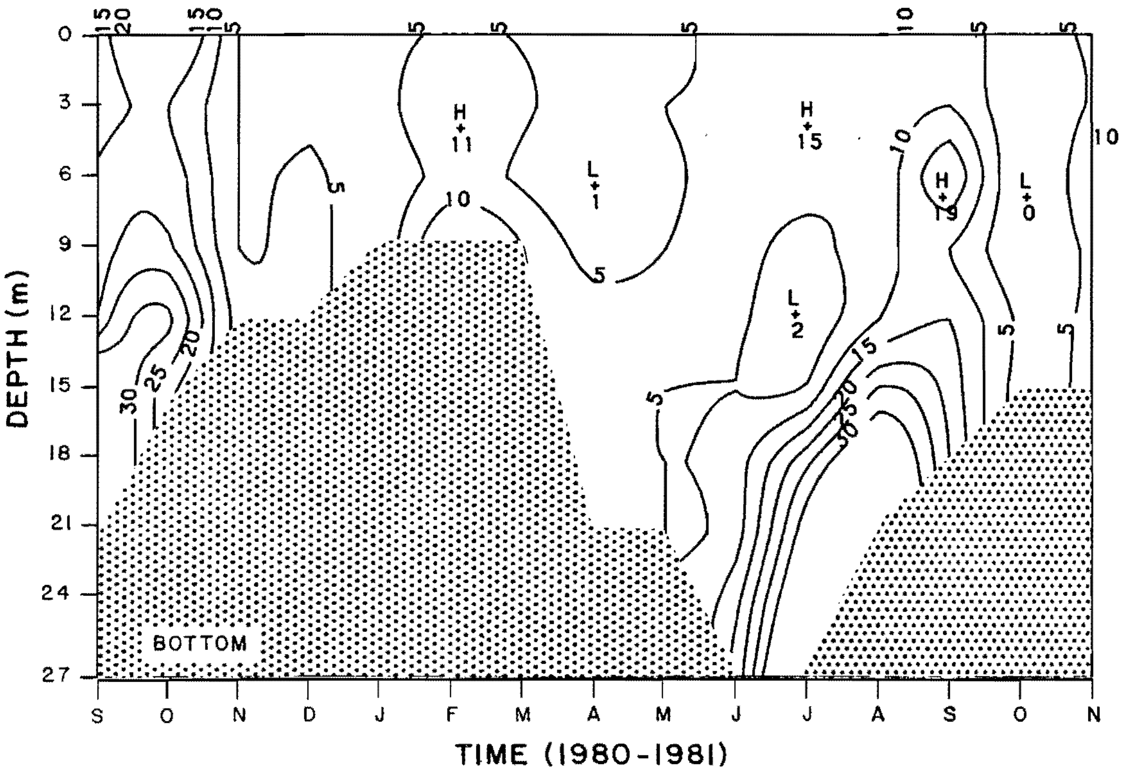

Figure 20. Orthophosphate concentration (µg P/l) isopleth for site C in Mt. Dell Reservoir.

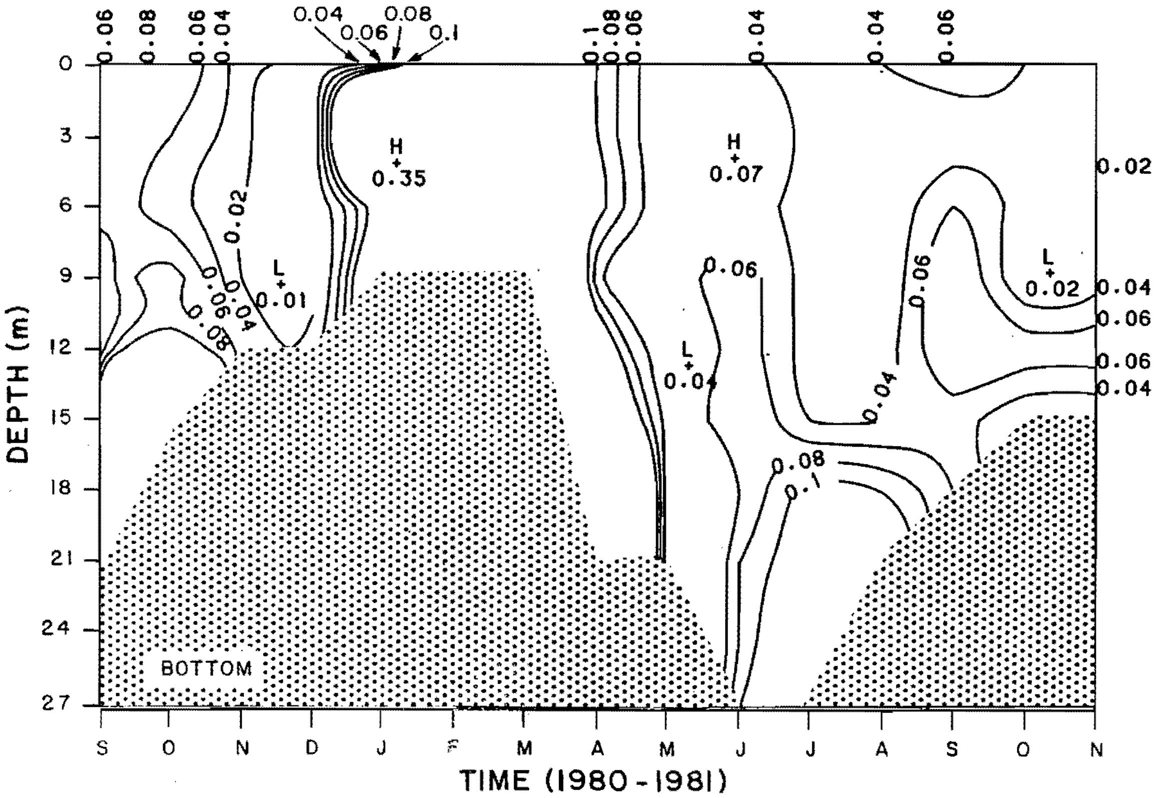

Figure 21. Total soluble inorganic nitrogen concentration (mg N/l) isopleth for site C in Mt. Dell Reservoir.

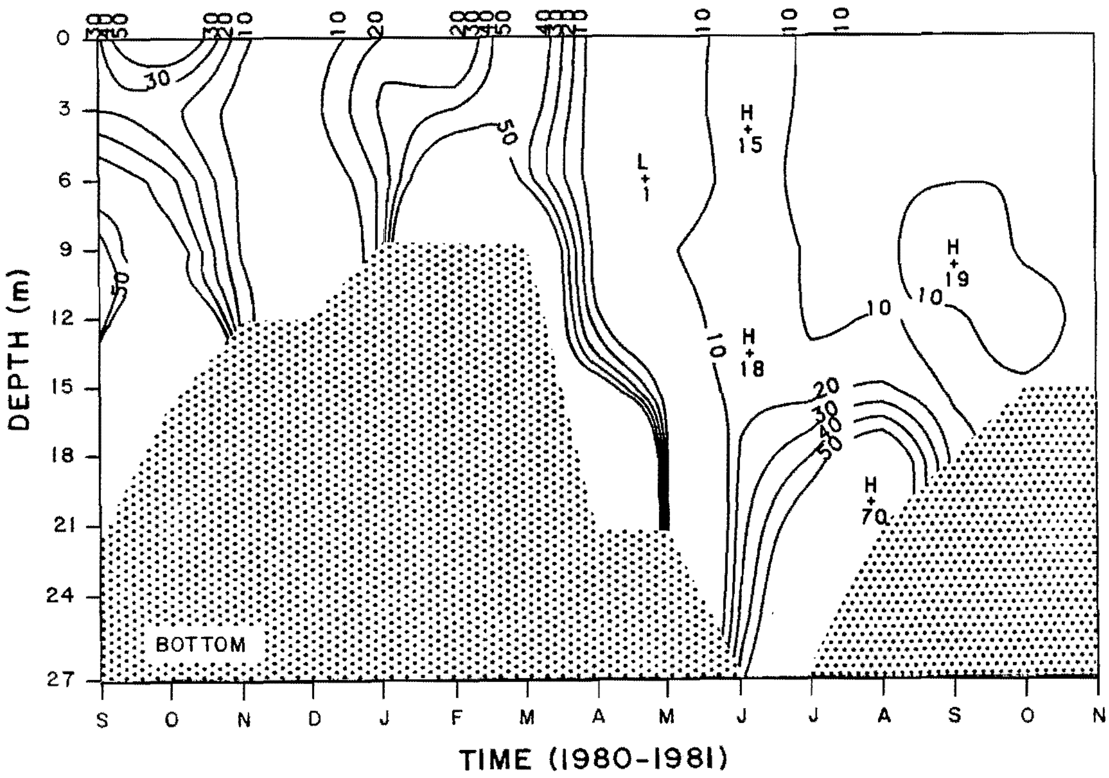

Figure 22. Ammonia concentration (µg N/l) isopleth for site C in Mt. Dell Reservoir.

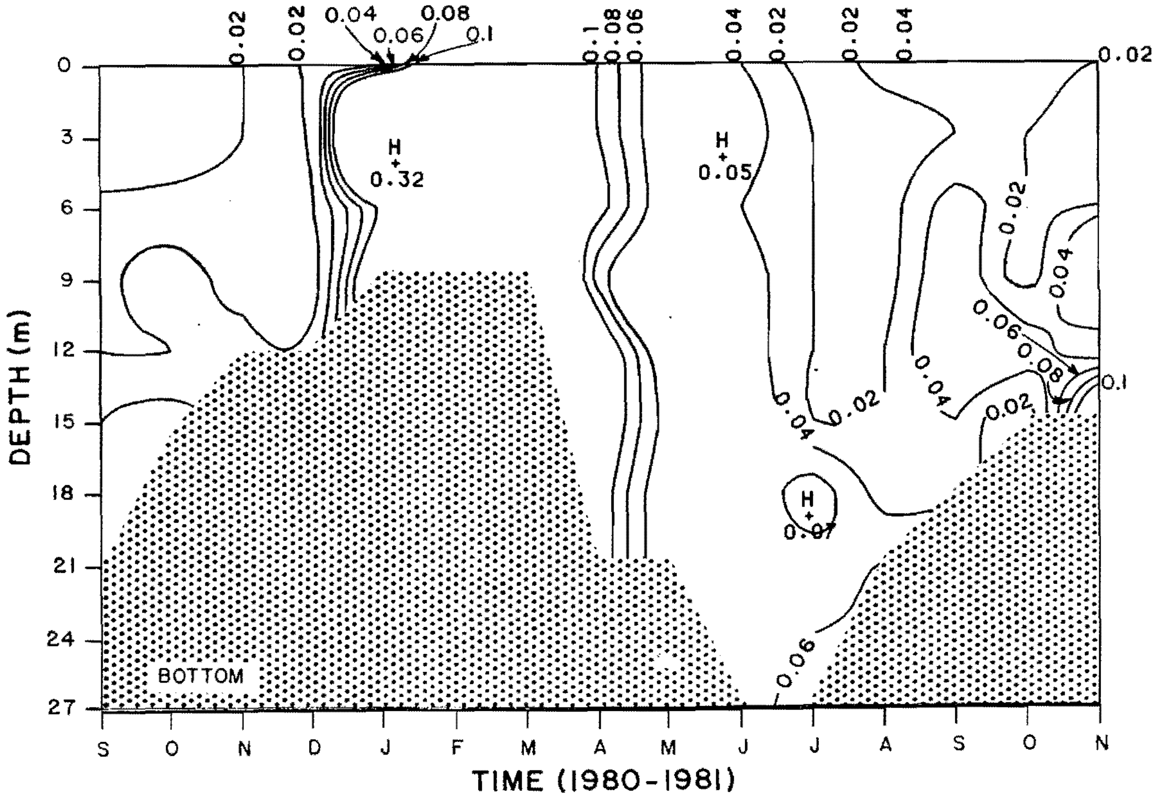

Figure 23. Nitrate plus nitrite concentration (mg N/l) isopleth for site C in Mt. Dell Reservoir.

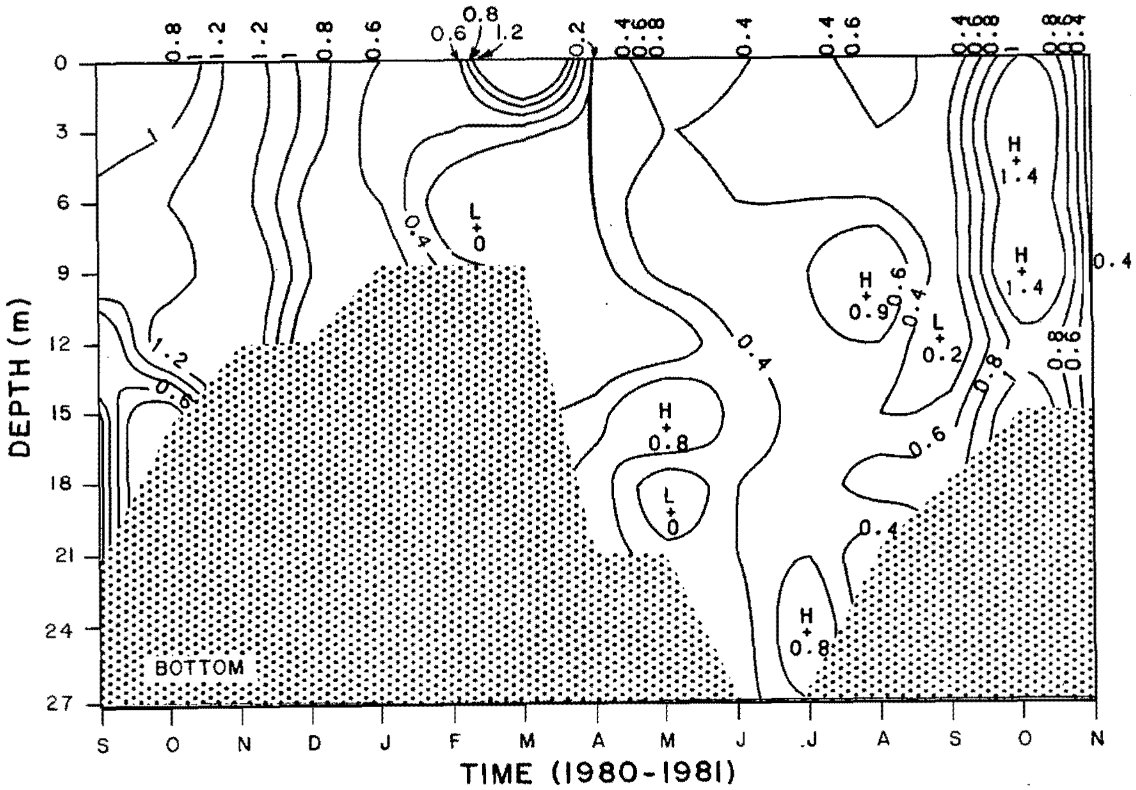

Figure 24. Organic nitrogen concentration (mg N/1) isopleth for site C in Mt. Dell Reservoir.

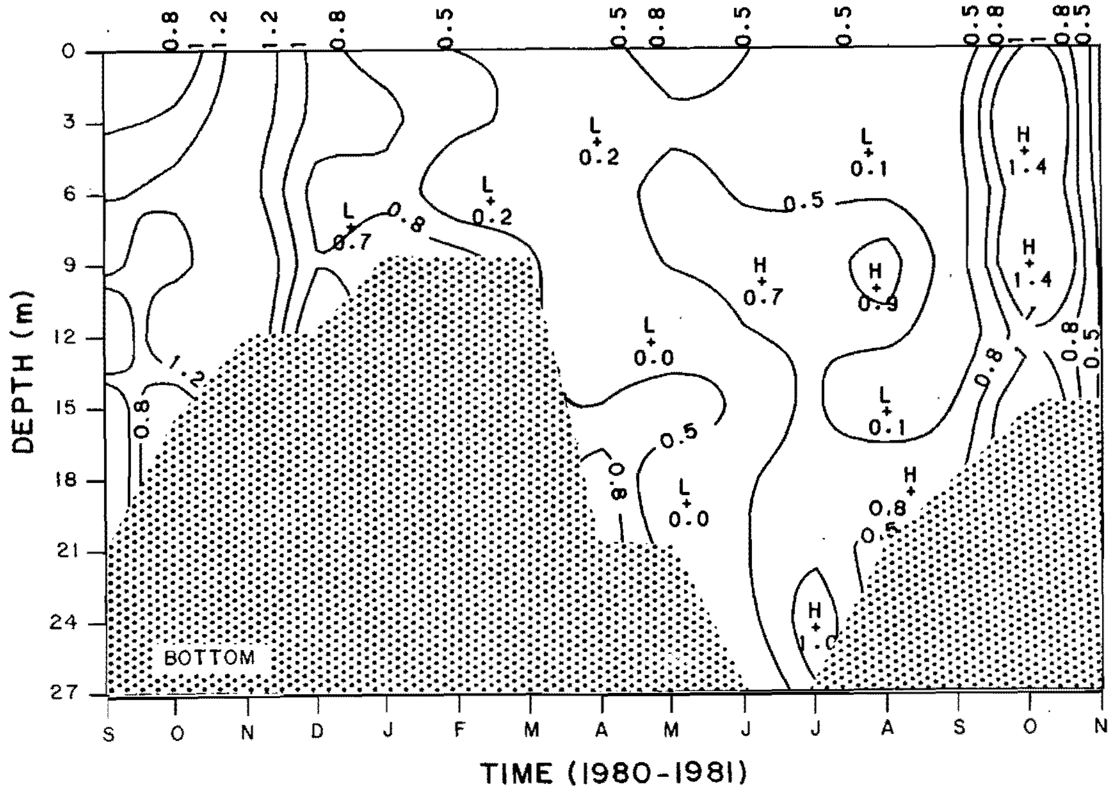

Figure 25. Total nitrogen concentration (mg N/1) isopleth for site C in Mt. Dell Reservoir.

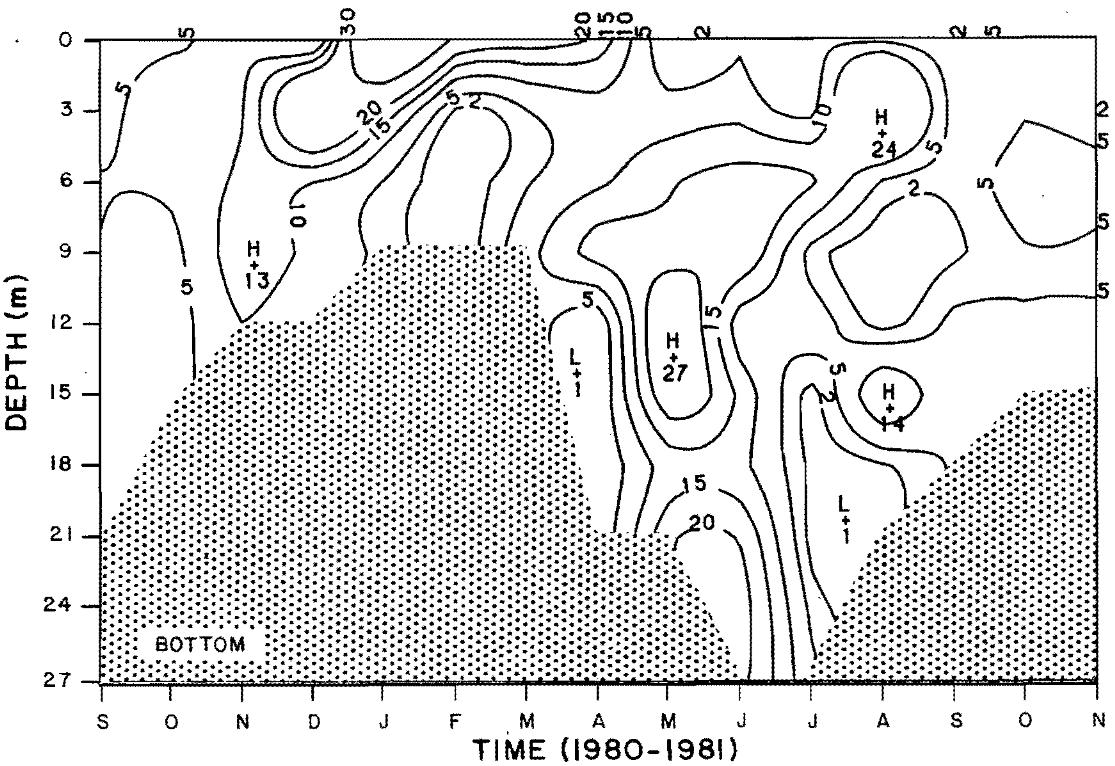

Figure 26. Uncorrected chlorophyll concentration (μg/l) isopleth for site C in Mt. Dell Reservoir.

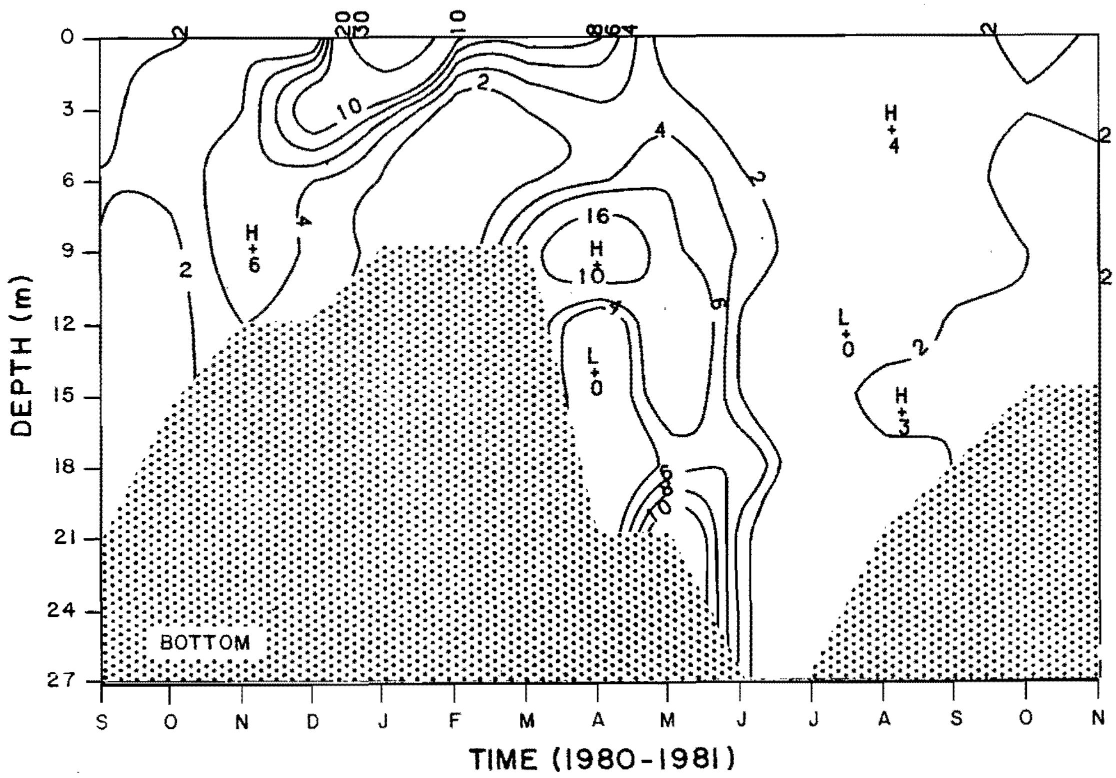

Figure 27. Chlorophyll a concentration (μg/l) isopleth for site C in Mt. Dell Reservoir.

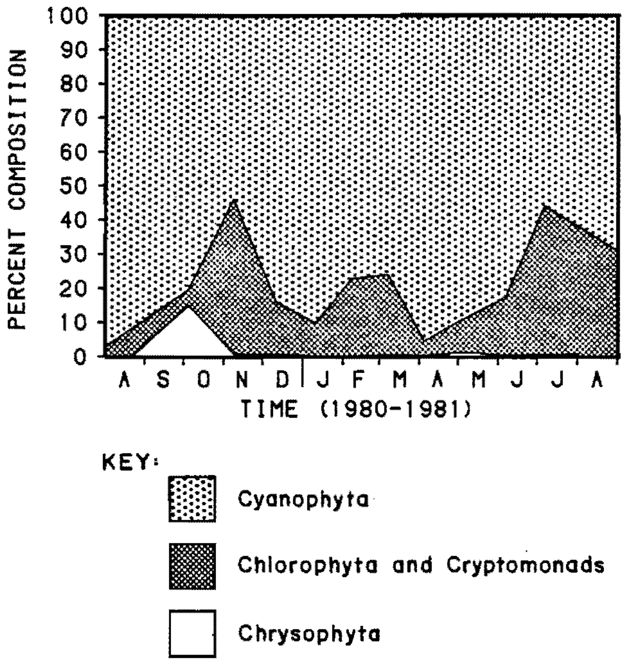

Figure 28. Percent composition of algal types in Mt. Dell Reservoir during the study period.

Low summer values may have been due to calcium carbonate precipitation (Messer et al. 1981).

Secchi transparencies ranged from 0.8 to 3.7 m and were similar with respect to location but differed seasonally (Table 15). Lower values were found during the winter when ice cover and high algal populations were present, and during the spring when stream runoff introduced turbidity. Relative vertical illuminations followed the same trend. Maximum light penetrations occurred during late spring and summer whereas lowest penetrations occurred during the winter. The lower limit of the photic zone (0.1 percent light level) was consistently found at half of the maximum depth.

Total phosphorus levels normally ranged from 10 to 76 µg/l while orthophosphorus levels usually ranged from 1 to 30 µg P/l (Figures 19 and 20). A number of high values (Tables 32 and 33) were obtained from bottom collected water samples, and it was suspected that sediment disturbance caused these high values. Orthophosphorus concentrations were generally higher during the fall and at greater depths. Total phosphorus concentrations varied with depth and season. Higher concentrations were found near the reservoir's bottom or at depths which contained relatively high chlorophyll concentrations.

Nitrogenous compounds followed similar trends. TSIN nitrogen (Figure 21) was highest during the winter and early spring. Although ammonia concentrations were relatively high during fall and winter, $(NO_3 + NO_2)$-N concentrations were high only in winter (Figures 22 and 23). The highest ammonia concentrations coincided with the lowest dissolved oxygen concentrations. Organic nitrogen (Figure 24) ranged from 0.0 to 1.6 mg/l with higher values occurring during the fall. Other seasons usually contained less than 1.0 mg/l. Total nitrogen (Figure 25) ranged from 0.02 to 1.76 mg/l and followed the same seasonal pattern as organic nitrogen.

Chlorophyll a concentrations ranged from 0.0 to 36.8 µg/l while uncorrected values ranged from 0.2 to 53.7 µg/l (Figures 26 and 27). Chlorophyll a concentrations peaked during the winter when copper sulfate was not applied and varied over the other seasons. Summer values of chlorophyll a were generally 5.0 µg/l or less while summer uncorrected values (up to 40 µg/l) were higher than any other season except for the winter algal blooms at the surface. Many months exhibited varied concentrations with depth with the highest values found at 3-12 meters in depth. During the summer it was common to find relatively high chlorophyll a values below the photic zone.

ANOVA analyses did not indicate significant differences in total phosphorus, orthophosphate, total nitrogen, TSIN, and chlorophyll concentrations with respect to reservoir location during June, July, or August (Appendix E). However, total phosphorus concentration did significantly differ with location during July. The general lack of significant differences is consistent with most studies. Statistical analyses were not performed with data from other seasons because sites J, D, and P were dewatered.

Algal counts indicated seasonal changes in algal populations (Figure 28 and Appendix F). Flagellates (mostly _Chlamydomonas_ sp., but also _Pedinomonas_, _Cryptomonas_, _Carteria_, and _Trachelomonas_ spp.) coincided well with chlorophyll _a_ levels. Peak levels were attained during the winter and at depths of 3-12 meters during the summer. Flagellates were present below the photic zone during the summer but were low in numbers. In general, flagellate numbers were higher during the winter and summer than in spring or fall. Diatoms (_Navicula_, _Nitzschia_, _Melosira_, _Meridion_, _Diatoma_, and _Eunotia_ spp.) did not exhibit a typical spring bloom. Instead, peak numbers occurred during the fall. One unknown filamentous Cyanophyte type occurred in very low numbers except during the summer when peaks occurred in the upper 6 meters. Another unknown spherical type (<2 μm diameter) of Cyanophyta occurred in much larger numbers than any other organism. Counts greater than 50/ml for this organism occurred mainly during the fall and winter, and the month of May in the main basin. Site J contained >50/ml counts at depths greater than 3 meters during June and near the bottom and surface during May and August respectively. Site P exhibited the same trend except >50/ml counts for May and August were just the opposite relative to depth. Site D consistently contained less than 50 organisms/ml during the summer.

Nutrient Limitation

The nutrient limitations at sites C (at the downstream end of the reservoir, Figure 1), DG, and PG (near where Dell and Parleys Creeks, respectively, flow into the reservoir, Figure 2) are summarized in Table 16. Algal bioassay maximum standing crops (MSC), a summary of statistical analyses, chemical ratios, and chemical analyses are given in Appendix G.

Algal bioassay tests indicated co-limitation for both stream waters for the whole year and Mt. Dell Reservoir water was co-limited throughout most of the year except in March (nitrogen limited) and July (phosphorus limited).

Total soluble inorganic nitrogen (TSIN):orthophosphate (PO_4-P) ratios were quite variable (see Appendix G). Water in the reservoir (site C) was generally indicated as phosphorus limited during the winter and spring and nitrogen limited during the summer. Water from stream site DG was generally co-limited throughout the year (Table 16), however, phosphorus limitation occurred during July whereas nitrogen limitation occurred during May, September, October, and December. TSIN:PO_4-P ratios of water from site PG indicated phosphorus limitation during the winter, co-limitation during the summer, and either nitrogen or phosphorus at other times. TSIN:PO_4-P ratios based on total stream loading indicated winter phosphorus limitation, variable spring and summer limitations, and nitrogen limitation during the fall.

Total nitrogen (TN):total phosphorus (TP) ratios of water from site C indicated winter nitrogen limitation, late spring and fall phosphorus limitation, and summer nitrogen or phosphorus limitation. TN:TP ratios of water from site DG did not follow any seasonal

Table 16. Nutrient limitation according to algal bioassays and chemical ratios.[a]

Limitation Method		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Algal Bioassays													
Sites[b]	C	N/P	N/P	N	N/P	N/P	N/P	P	N/P	N/P	N/P	N/P	N/P
	DG	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P
	PG	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P	N/P
TSIN:PO_4-P Ratios													
Sites	C	P	P	N	P	P	N/P	N	N	N/P	P	N	P
	DG	N/P	N/P	N/P	N/P	N	N/P	P	N/P	N	N	N/P	N
	PG	P	P	P	N/P	N	N/P	N/P	N/P	P	N	N	N/P
Total Stream Loading		P	P	P	N/P	N	N/P	P	N/P	N	N	N	N/P
TN:TP Ratios													
Sites	C	N	N	N	N	P	P	N	P	N/P	P	P	-
	DG	P	N	P	N	P	P	N/P	N/P	N/P	P	N	-
	PG	P	N/P	N/P	N	N/P	N/P	N	N/P	P	P	N	-
Total Stream Loading		P	N	N/P	N	P	N/P	N	N/P	P	P	N	-

[a] Where P = phosphorus limitation, N = nitrogen limitation, and N/P = co-limitation. Missing data is due to inadvertant disposal of sample.

[b] The sites are shown in Figures 1 and 2.

trends (Table 16) except during the summer (co-limitation). TN:TP ratios of water from site PG indicated a dominance of co-limitation although phosphorus seemed to be limiting during the fall. Total stream loading TN:TP ratios were similar to the ratios of site PG.

The algal bioassay results suggested that either phosphorus or nitrogen could limit algal productivity. Although most lake management schemes are oriented towards phosphorus control, it may be more practical to control nitrogen. This study found that the area between sites DUP and DG contributed significant amounts of TSIN to Dell Creek. Controlling TSIN inputs from this area could limit algal biomass in the reservoir if nitrogen gas fixation by blue-green algae was minimal.

Unfortunately, blue-green algae were dominant (Figure 28) throughout the year, and their nitrogen fixing capabilities could minimize the effects of nitrogen reduction in the watershed. A potential remedy is suggested in the findings of Horne and Goldman (1972) that sublethal doses of copper sulfate (∿5-10 μg Cu/l) poison enzymes that are required for nitrogen fixation. Thus, the competitive advantage of blue-green algae during times of nitrogen limitation could be minimized by sublethal doses of copper sulfate.

The copper sulfate applications to Mt. Dell Reservoir could be sublethal. Bartlett et al. (1974) reported that copper was algicidal to Selenastrum capricornutum at 300 μg/l while complete growth inhibition required 90 μg/l and initial growth inhibition required 50 μg/l copper. Only during July and August did the algal bioassay reservoir water contain copper concentrations greater thar 300 μg/l (Appendix G). Interestingly, the algal bioassay toxicity tests did not indicate metal toxicity during August although the very low July MSC values for all treatments suggested either toxicity or laboratory error.

Typical copper sulfate dosages for Mt. Dell Reservoir ranged from 300 to 1200 pounds per treatment and were intended to treat the upper 3 meters of the water column. Assuming that the copper was confined to this zone, these doses would result in a copper concentration range of 60 to 250 μg Cu/l in the uppermost 3 meters of water. Thus, the higher doses of copper sulfate would be algicidal to S. capricornutum. Considering that the indigenous algae take at least 50 years to develop tolerance, concentrations greater than 300 μg Cu/l may be required for effective control of indigenous species.

If the copper sulfate applications were indeed sublethal, then the competitive advantage of blue-green algae would be decreased, and a decrease in blue-green algal dominance would result. Figure 28 indicates a decrease in dominance of blue-green algae during the summer (the major season of copper sulfate application) and thus suggests that the blue-green algae have lost their competitive advantage and that reduction of nitrogen inputs could reduce the algal biomass in the reservoir.

The TN:TP ratios also suggests sublethal doses of copper sulfate. For example, during early spring when copper sulfate is not applied, the reservoir surface water was nitrogen limited (Table 16) and blue-green algae dominated (Figure 28). During the summer copper sulfate application period, however, the dominance of blue-green algae decreased although nitrogen was again limiting.

The TSIN:PO4-P ratios suggested a direct effect of algae on nutrient limitation. For example, chlorophyll a concentrations were high and orthophosphate levels were low during periods of phosphorus limitation. Therefore, caution should be used in the interpretation of algal populations in a rapidly changing state.

The copper sulfate applications (either algicidal or sublethal) certainly affected algae. These applications killed at least a portion of algae which had utilized some of the PO_4-P in the water column (Figure 29). Lysis of dying cells can liberate much of the cellular phosphorus as PO_4-P in a matter of days (Gachter 1968; Golterman 1973). Thus, rapid recycling of PO_4-P could shift waters from a phosphorus to a nitrogen limitation. In addition, algal luxury uptake of phosphorus may cause nitrogen limitation when in fact phosphorus is the limiting nutrient at the time of sampling (Fitzgerald 1969; Lee 1973). Miller et al. (1974) found that phosphorus limitation decreased as lake water productivity increased, and Vollenweider (1975, 1976) also presented evidence that beyond certain advanced levels of eutrophication, water may shift from phosphorus to nitrogen limitation. With respect to the conclusions of Miller et al. (1974), Mt. Dell Reservoir surface waters during the summer would be more productive than at other times. During the winter, the reservoir would have low productivity since the waters are phosphorus limited. Perhaps the copper sulfate applications are decreasing algal biomass but keeping algal productivity high. Further research is needed.

Since TSIN:PO_4-P ratios are difficult to interpret if lake conditions change rapidly or algal luxury consumptions exist, Forsberg (1980) recommended the use of TN:TP ratios. These ratios do not account for assimilable forms of nutrients and are therefore less sensitive to changes in algal populations and luxury up-

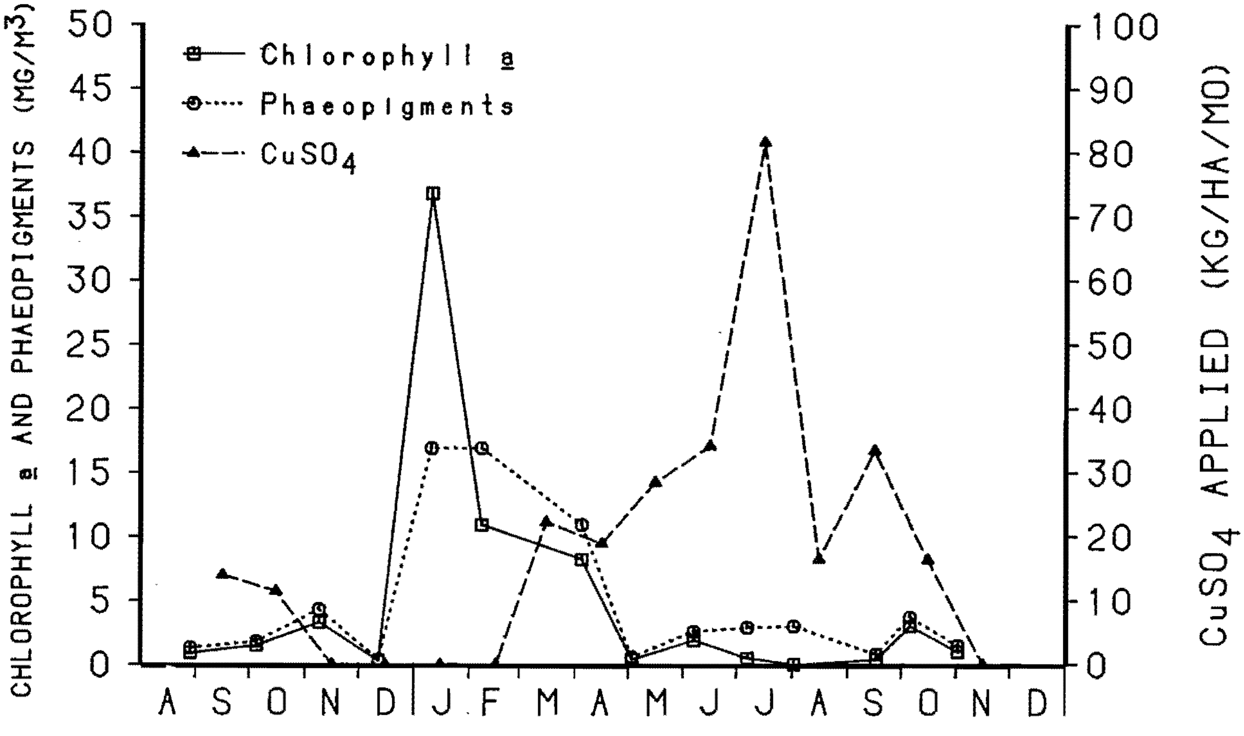

Figure 29. Surface chlorophyll a and phaeopigment concentrations (µg/l) of site C and copper sulfate applications during the study period.

takes. Forsberg further believes that TSIN:PO_4-P ratios reveal which nutrient limits algal productivity, whereas TN:TP ratios delineate the nutrient which limits algal biomass. Water managers are more likely to be interested in algal biomass than in algal productivity. Thus the TN:TP ratios could be of a more practical use than are algal bioassays or TSIN:PO_4-P ratios.

The TN:TP ratios generally supported Forsberg's opinions with respect to algal biomass. Chlorophyll a levels were highest during the winter. Phosphorus limitation in the reservoir during the summer is of special interest because most trophic state indices are based on summer conditions and the resultant algal biomass. The time patterns of these ratios partially validate the use of phosphorus-chlorophyll a based indices.

TN:TP or TSIN:PO_4-P ratios of water from the stream sites did not coincide well with the chemical ratios of reservoir water. This was not unexpected because these ratios probably reflect the dynamics of each type of system (i.e., stream and reservoir) besides the relationship between the two.

For example, the copper sulfate applications apparently affected algal biomass (Figure 29) and may have indirectly affected the reservoir's TSIN:PO_4-P ratios via rapid nutrient recycling, whereas the stream ratios were not influenced by copper sulfate. Hydrologic factors may also have caused the discrepancy between reservoir and stream water chemical ratios. Summer water densities (Appendix H) indicate that stream water would not enter the reservoir as an overflow but as an interflow or underflow. It is also possible that much of the total phosphorus or total nitrogen entering the reservoir is present as particulates which settle out. Specific evidence for this, however, is lacking.

Trophic State Indices

The indicated trophic state of the reservoir ranged from oligotrophy to eutrophy according to the indices used (Table 17). Oligotrophy was indicated with summer chlorophyll based indices, the LEI model's oxygen and macrophyte variables, and Palmer's organic pollution index. Summer total phosphorus, total nitrogen, Secchi transparency indices, and Vollenweider's (1976) loading model resulted in mesotrophic or eutrophic classifications.

Carlson's trophic state index (TSI) values for Secchi transparency, total phosphorus, and chlorophyll a were calculated monthly and are presented in Figure 30. According to these data, the reservoir varies from oligotrophy to eutrophy depending on the time of year and the particular TSI. TSI (TP) values suggested eutrophy for most of the year except November and December (mesotrophy). TSI (SD) values indicated eutrophy during the winter and early spring and mesotrophy the rest of the year. Chlorophyll a TSI values indicated mainly oligotrophy except during the winter (eutrophy).

Figure 31 presents monthly areal copper sulfate applications to the reservoir, and these data coincide well with the breakdown of TSI parallelisms. TP and SD TSI values remained relatively parallel during copper sulfate applications whereas chlorophyll a TSI values decrease.

The apparent insensitivity of TP and SD TSI values to copper sulfate applications may be caused by slow sinking rates of dead and dying cells and their associated phosphorus. Slow sinking rates would tend to retain the effect of these variables on epilimnetic conditions. Seasonally, these indices were highest during midwinter and reflected the larger winter algal populations.

Table 17. The trophic state of Mt. Dell Reservoir according to various trophic state indices.

Method	Parameter of Interest	Value	Trophic State	Reference
Carlson's TSI	Total phosphorus	50.0	Eutrophic	Carlson (1977)
Carlson's TSI	Chlorophyll *a*	21.7	Oligotrophic	Carlson (1977)
Carlson's TSI	Secchi transparency	44.6	Mesotrophic	Carlson (1977)
LEI Model	Total phosphorus	54.0	Eutrophic	Porcella et al. (1980)
LEI Model	Chlorophyll *a*	25.1	Oligotrophic	Porcella et al. (1980)
LEI Model	Secchi transparency	45.4	Mesotrophic	Porcella et al. (1980)
LEI Model	Macrophytes	0.0	Oligotrophic	Porcella et al. (1980)
LEI Model	Dissolved Oxygen	32.1	Oligotrophic	Porcella et al. (1980)
LEI Model	Total Nitrogen	65.5	Eutrophic	Porcella et al. (1980)
LEI Model	Composite (using TP)	31.3	Oligotrophic	Porcella et al. (1980)
LEI Model	Composite (using TN)	33.6	Oligotrophic	Porcella et al. (1980)
Palmer's Index	Algal genera	<15	Oligotrophic	Palmer (1969)
Vollenweider's Loading Model[a]	Chlorophyll *a*	9.0 mg/m^3	Mesotrophic	Vollenweider (1976)
Vollenweider's Loading Model[a]	Total phosphorus	34 mg/m^3	Eutrophic	Vollenweider (1976)

[a] Using average hydrologic regime

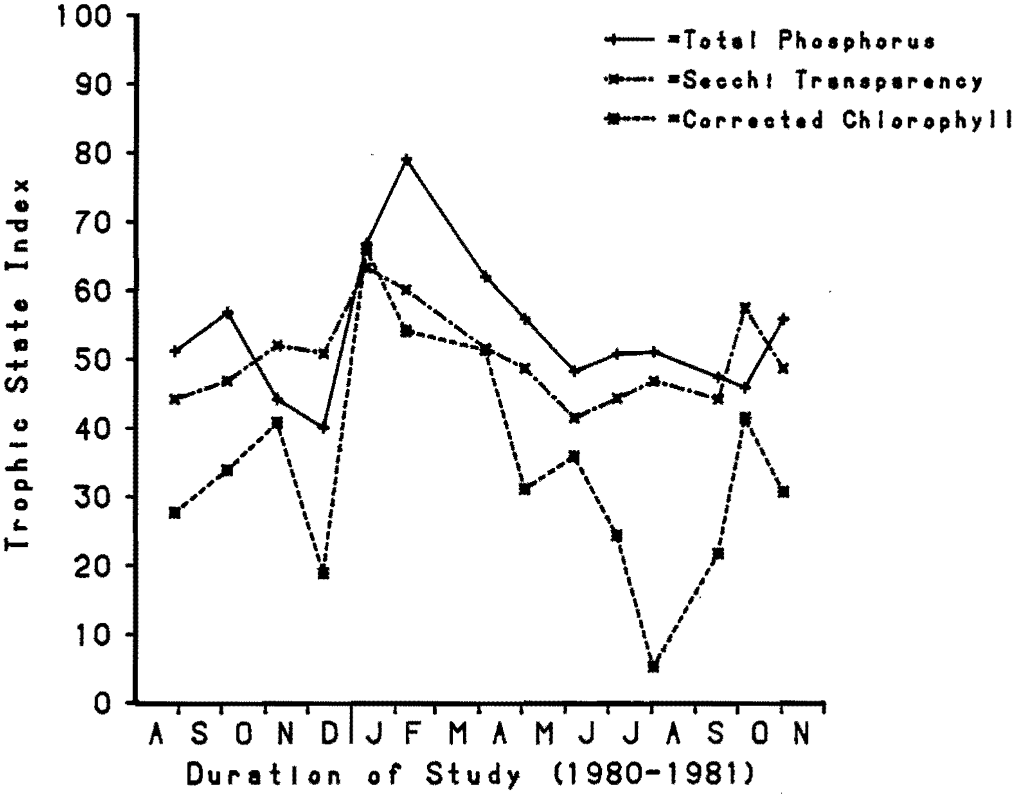

Figure 30. Carlson's trophic state indices for Mt. Dell Reservoir.

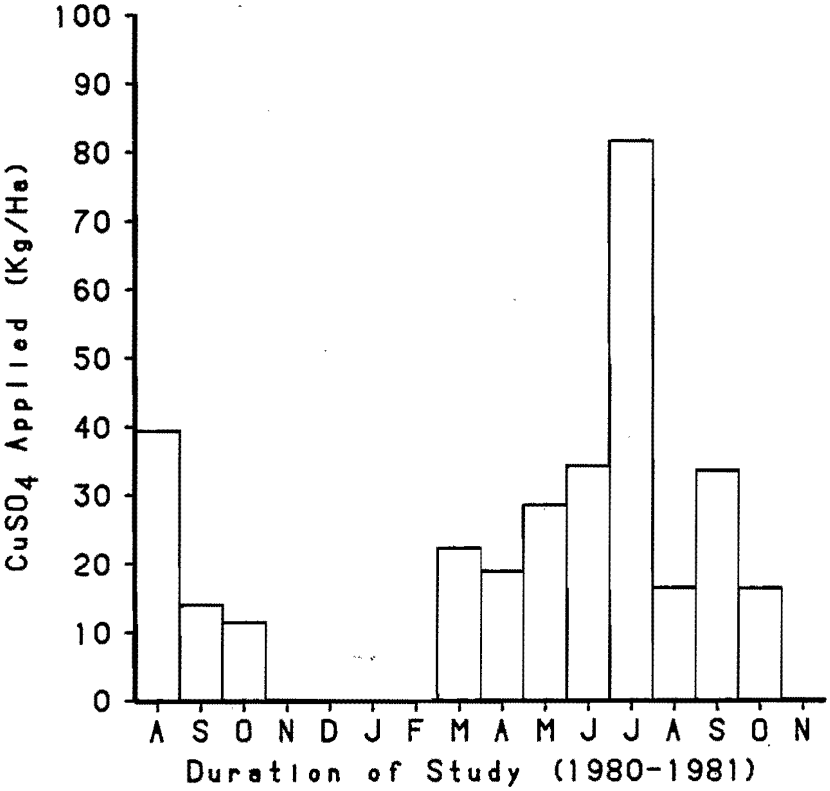

Figure 31. Copper sulfate applied to Mt. Dell Reservoir.

The chlorophyll TSI was more sensitive to copper sulfate applications. Figure 29 illustrates the relationship between copper sulfate application and surface chlorophyll a and phaeopigment concentrations. Surface chlorophyll a and phaeopigment levels were highest during the winter when copper sulfate was not applied and dropped below 5 μg/l when copper sulfate was applied.

This suggests the possibility of using Carlson's chlorophyll index for detecting algal perturbation causes. Carlson (1980) presented evidence relating chlorophyll TSI values to zooplankton densities and found that the lowest chlorophyll TSI values coincided with the highest zooplankton densities.

The LEI model of Porcella et al. (1980) suggested an oligotrophic system, regardless of whether total nitrogen or total phosphorus was used in the composite index. Using TP instead of TN, the LEI value was 31.3 while TN based calculations produced a value of 33.6. Porcella et al. (1980) suggested that oligotrophic systems have values less than 40-45 while values greater than 50 indicate eutrophy.

Since the LEI model is in part derived from Carlson's (1977) regression equations, one would expect similar resultant trophic states. This was true when the LEI variables are taken separately (see Table 17). Total phosphorus, Secchi transparency, and chlorophyll a LEI variables indicated trophic states similar to those indicated by Carlson's indices. However, the addition of two other variables (oxygen and macrophytes) caused an oligotrophic description in the composite indices.

The oxygen variable indicated oligotrophy (Table 17) which seems inappropriate in this case because systems with repeated algal blooms are usually not oligotrophic. The summer stratification patterns were very weak and could be indicative of mixing and reaeration of the hypolimnion. Oxygen concentrations in the hypolimnion may be further complicated by stream water underflows or lower port withdrawals (Wunderlich 1971). This is apparently the case in Mt. Dell Reservoir. The lower port is not used extensively but it is left slightly open to prevent siltation of the intake. Hutchinson (1957) and Charlton (1980) expressed concern over using oxygen deficits in shallow systems because of possible allochthonous organic inputs and morphometric and hydrodynamic complications.

The macrophyte variable represents the percentage of macrophyte coverage. For this reservoir, the percentage would be zero since macrophytes were not present. This essentially reduced the LEI composite model by one variable and certainly weighted the value towards oligotrophy.

Porcella et al. (1980) assumed that high quality lakes generally have few macrophytes. In some cases macrophyte density is more influenced by hydrodynamics than by lake and sediment nutrient concentrations. Lake and reservoir drawdowns have been commonly used as a means of controlling macrophytes (Kadlec 1962; Beard 1973; Dunst et al. 1974; Fox et al. 1977), and this reflects the importance of lake hydrodynamics to macrophyte density. In these cases, the macrophyte densities are generally independent of lake and sediment nutrient concentrations. Therefore, LEI models should not be applied to systems with repeated drawdowns or widely fluctuating water levels because they do not adhere to the general assumption given by Porcella et al. (1980). The LEI model is admittedly in the developmental stage, and modification or elimination of the macrophyte component may broaden its application.

The results of Palmer's algal genus pollution index inferred low organic pollution, unrepresentative sampling, or an interferring substance. This index may be of limited use for Mt. Dell Reservoir since copper sulfate applications are certainly an interferring substance.

Despite the inconclusiveness of the results, algal identifications and enumerations remain highly useful to water managers (McKnight et al. 1981; Ridley 1970). Other methods of measuring the algal standing crop do not display algal species changes, whereas enumeration and identifications provide insights to potential problems because of differences among algal species.

Tables 18 and 19 summarize phosphorus loadings to the reservoir and pertinent data required for Vollenweider's (1976) loading model. Appendix I contains hydrologic data used in the calculations.

According to these data, the mean summer epilimnetic chlorophyll a concentration was calculated to be 9.0 mg/m^3 (99 percent confidence intervals 5.5-15.5 using Vollenweider's limits) when 15 years of hydrologic data are used. This value differed greatly from the measured summer epilimnetic chlorophyll a concentration of 1981 (1.0 mg/m^3). Vollenweider's model was also used with 1980-1981 hydrologic data. Calculations produced a predicted value of 8.3 mg/m^3) which also differed from the measured value (Table 20). The predicted values indicated mesotrophy while measured chlorophyll a concentrations indicated oligotrophy.

The discrepancies between measured and predicted chlorophyll a concentrations would appear to be due to the copper sulfate applications. Algae are continually being destroyed throughout the summer with copper sulfate, and algal populations are probably not reaching their "natural" levels.

Comparisons of predicted and measured total phosphorus concentrations may circumvent the complications caused by copper sulfate. The volume weighted mean total phosphorus concentration during June, the last part of spring runoff and overturn, was about 35 mg/m^3. Predicted total phosphorus concentrations for both situations (15-year hydrology and 1980-1981 hydrology) were about 34 and 31 mg/m^3 respectively. These values are more similar to the measured total phosphorus concentration than predictions of chlorophyll a (Table 20). Therefore, Vollenweider's (1976) loading model could still be used as a management tool for predicting total phosphorus concentrations.

Interestingly, the measured mean summer epilimnetic uncorrected chlorophyll (chlorophyll a + phaeophytin) concentration of 8.3 mg/m^3 matched the predicted chlorophyll a concentration when 1980-1981 hydrologic data were used. Can uncorrected chlorophyll concentrations be used in place of chlorophyll a concentration? In this reservoir, uncorrected chlorophyll concentrations may be more representative of "natural" algal biomass levels.

Baker and Adams (1982) applied Vollenweider's (1976) loading model to Intermountain lake and reservoir systems. Systems that did not accurately predict mean summer epilimnetic chlorophyll a concentrations were those which were not completely phosphorus limited throughout the year, those which contained macrophytes, or those that were moderately to highly turbid. Mt. Dell Reservoir does not contain macrophytes and is generally clear. The reservoir was not completely phosphorus limited throughout the year and hence the possibility for poor predictive capabilities. Nevertheless, the similarity between measured and predicted total phosphorus levels indicate that this model could be a useful management tool.

Areal phosphorus loadings and critical loadings were calculated monthly for an average flow year (15-year average) and a moderately dry year (1980-1981) to see when critical load-

Table 18. Phosphorus loadings from Parleys Creek (P) and Dell Creek (D).

Month	Creek	Inflow (cfs)	Total P (mg/l)	P Loading (kg)
Sep.	D	2.50	0.021	3.85
	P	5.26	0.021	8.11
Oct.	D	2.80	0.032	6.58
	P	4.72	0.034	11.78
Nov.	D	3.14	0.026	5.99
	P	4.21	0.026	8.03
Dec.	D	3.00	0.032	7.05
	P	3.78	0.027	7.49
Jan.	D	3.06	0.014	3.14
	P	3.64	0.011	2.94
Feb.	D	3.59	0.053	13.96
	P	3.81	0.044	12.30
Mar.	D	8.82	0.020	12.95
	P	7.78	0.020	11.42
Apr.	D	26.57	0.052	101.40
	P	17.83	0.044	57.58
May	D	46.10	0.047	159.01
	P	31.60	0.062	143.79
Jun.	D	18.00	0.046	60.77
	P	25.56	0.057	106.92
Jul.	D	5.54	0.027	10.98
	P	12.84	0.050	47.12
Aug.	D	2.96	0.031	6.73
	P	7.23	0.030	15.92
Annual Total		254.3		825.8

Table 19. Calculation of the mean summer epilimnetic chlorophyll a concentration in Mt. Dell Reservoir.[a]

Annual P Loading (kg)	825.81
Average Area (10^4 m^2d)	20.8471
Average Volume (10^6 m^3)	1.8863
Mean Depth (m) Z	8.69
Average Annual Inflow (10^6 m^3)	18.788
Areal P Loading, L_p ($mg/m^2/yr$)	3961.22
Areal Water Loading, q_s (m/yr)	90.12
$\frac{L_p/q_s}{1+\sqrt{\bar{z}/q_s}}$	33.55
Predicted Mean Summer Epilimnetic Chlorophyll a Concentration (mg/m^3)	8.98

[a]Using Equation 12 and a 15-year average hydrologic regime.

ings occurred seasonally and if different flow regimes caused differences in predicted chlorophyll a concentrations.

Figures 32 and 33 indicated relatively low phosphorus loadings except during spring runoff. The upper critical limit was exceeded during the spring in both cases. An average water year had three times the annual areal phosphorus loading of a moderately dry water year during spring runoff.

Despite these phosphorus loading differences, the predicted mean summer epilimnetic chlorophyll a concentrations were comparable (Table 20). This suggests that some sort of limiting effect may arise from the patterns in which the water from the lake is released to the treatment plant for delivery to the city. Vollenweider (1976), Dillon (1974, 1975), and Imboden (1974) have mentioned the importance of hydraulic flushing rates and their effect on phosphorus retention. High hydraulic flushing rates can lower phosphorus retentions and consequently lower lake phosphorus concentrations and algae.

The general strategy of Mt. Dell Reservoir operators has been to let the reservoir fill during the spring. The reservoir obviously takes longer to fill during "dry" years, and outflows are less. During "wet" years the reservoir fills more rapidly; and after reaching capacity, continuing inflow is released. Thus, phosphorus retentions might be limited during "wet" water years by an increased hydraulic flushing rate.

In summary, it has been concluded that Mt. Dell Reservoir is in a mesotrophic/eutrophic state.

Table 20. Measured and predicted total phosphorus and chlorophyll a levels for Mt. Dell Reservoir.

Parameter	Predicted Value[a] (1980-1981 Hydrology)	Predicted Value[a] (15 Year Average Hydrology)	Measured Value (1980-1981)
Total phosphorus at spring overturn (mg/m^3)	31.0	33.6	34.7
Mean summer epilimnetic chlorophyll a (mg/m^3)	8.3	9.0	1.0
Mean summer epilimnetic chlorophyll a + phaeophytin (mg/m^3)			8.3

[a] Based on Vollenweider's (1976) loading model.

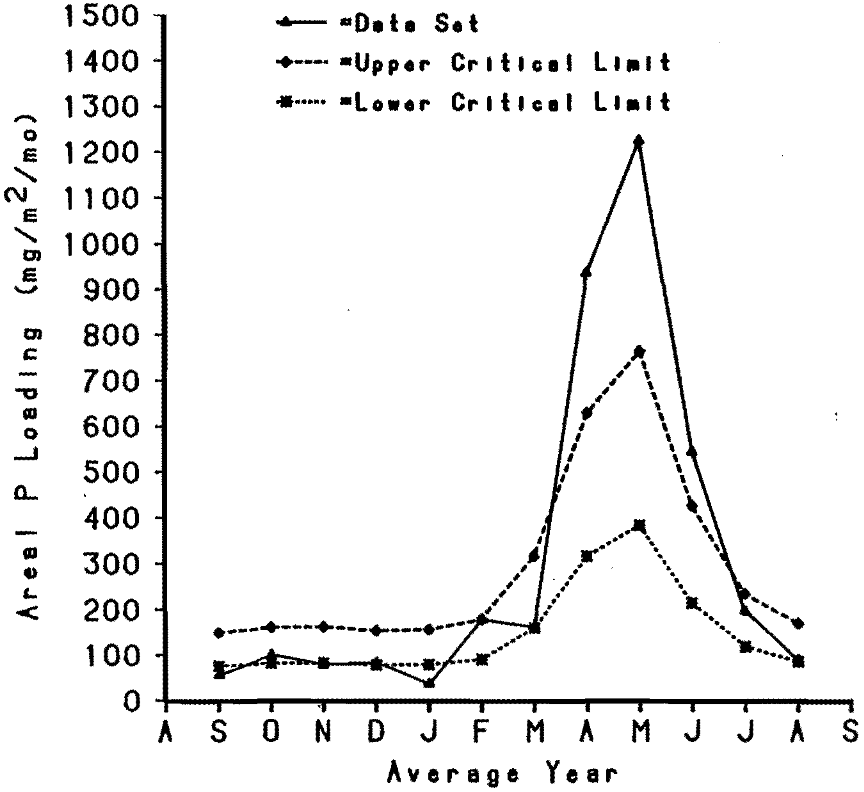

Figure 32. Areal P loadings to Mt. Dell Reservoir during an average water year (based on a 15-year average).

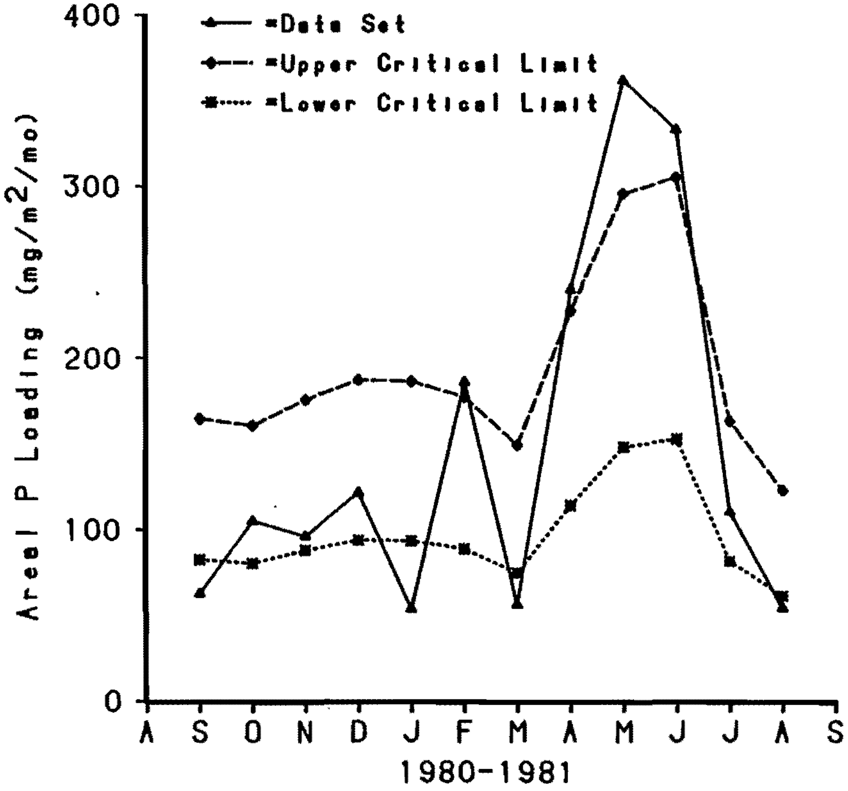

Figure 33. Areal P loadings to Mt. Dell Reservoir during a dry water year (1980-1981).

RESTORATION TECHNIQUES

Overview and Impractical Techniques

Numerous lake and reservoir restoration strategies are presently available, and these can be grouped into two general categories: methods which reduce nutrient or sediment loading and methods which deal with the consequences of lake aging (Dunst et al. 1974). The first approach addresses the underlying causes of eutrophication while the second ameliorates its manifestations.

The nutrient loading/trophic response concept (Vollenweider 1968) provides the basic framework for the first approach. Generally speaking, decreased nutrient loading improves water quality. Various methods can reduce external nutrient supplies. Methods for reducing nutrient inflow include wastewater treatment, land treatment to reduce runoff and soil erosion, diversion of nutrient laden inflows, dilution with nutrient poor waters, and treatment to reduce nutrient concentrations in inflowing waters. Other methods reduce in-lake nutrient sources by dredging, bottom sealing, drawdown, and nutrient inactivation/precipitation.

The second approach deals with such consequences of eutrophication as algae, hypolimnetic anoxia, macrophytes, and sedimentation. Methods include biotic harvesting, lake drawdown, dredging, aeration/circulation, and chemical and biological controls.

The selection of restoration methods should be based on scientific assessment of probable results, cost effectiveness, and various practical considerations. A number of the aforementioned techniques are not considered viable for the Mt. Dell Reservoir situation. For example, there is no wastewater discharge into the lake. Inflow treatments (see Bernhardt and Schell 1982) can decrease nutrient loading from inflowing waters, but costs are high. Dilution requires a source of nutrient-poor dilution water. Water diversion is only practical for systems where nutrients come from point sources. Bottom sealing with fly ash or polyethylene sheeting may cause more harm than benefits (Cooke 1980), but $Al_2(SO_4)_3$ inactivation may be feasible if anoxic conditions occur. Biological control of algae was not considered in this study because of the lack of knowledge about this technique (Shapiro 1979). Lake drawdown was not considered because of the relatively rigid annual pattern of lake levels imposed by water demands.

Finally, land treatment to reduce nutrient loading from nonpoint sources was not considered because of inadequate information on what various techniques would achieve. However, this study did suggest that the agricultural and/or the undisturbed rangeland on Dell Creek contributed statistically significant amounts of total soluble inorganic nitrogen (TSIN) to the stream. Further research is required to determine the TSIN contributions from each land use area and methods that would reduce those loadings.

The remaining restoration techniques are mainly in-lake procedures, and these are summarized in Table 21 and discussed on the following pages. In-lake methods are usually short term solutions (Dunst et al. 1974).

Table 21. Summary of feasible restoration techniques and their advantages and disadvantages.

Restoration Technique	Advantages	Disadvantages
Algicides ($CuSO_4$)	Easy application, immediate results	Development of tolerance in algae, need for repeated treatments, toxicity to zooplankton, benthic animals, and fish
Selective withdrawal	Multiple effects, easily applied	Possible increased algal biomass at lower depths, siltation caused problems of water treatment, elimination of cold water fisheries
Aeration/ circulation	Multiple effects	Possible increased turbidity, possible increased nutrient and algal concentrations in photic zone, elimination of cold water fisheries
Sediment removal	Economical means of increasing capacity, removal of potential THM precursors	Temporary increased turbidity, temporary elevated nutrient and algal concentrations in water column, destruction of benthic communities
Phosphorus inactivation/ precipitation	Immediate effectiveness, generally innocuous to biota	Elevated dissolved aluminum levels, decreased pH and alkalinity, need for repeated treatments

Feasible Restoration Strategies

Algicides

Algicides can be a reasonable short term algal bloom control option. Many algicides are available, but the majority are limited to systems that do not supply water for domestic use because of possible side effects to man and other organisms (Dunst et al. 1974). Copper sulfate has been used to control algae for nearly a century, and it is probably the most widely used algicide today (Muchmore 1976). McKnight et al. (1981) reviewed copper sulfate control measures and discussed various advantages and disadvantages. The major disadvantages included the need for repeated treatments; toxicity to other organisms; inadequate control of blue-green algal blooms; and the development of copper resistant species. Advantages included ease of application and rapid effect.

The repeated copper sulfate applications to Mt. Dell Reservoir water indicate a strong concern over the presence of algae and perhaps imply ineffective applications. Application decisions have been based on sporadic Secchi transparency readings, visual observations, personal experiences, and algal enumerations of surface water samples (personal observation). This study showed relatively high chlorophyll levels, i.e. algal biomass, at depths of 3-9 meters (Figures 26 and 27). Therefore, algal enumerations of surface water samples may be inadequate to assess algal biomass or population levels. Likewise, Secchi transparency readings and visual observations may not detect the effects of subsurface algae. Consideration should be given to collecting subsurface water samples for analyses.

Copper sulfate application effectiveness is partially illustrated in Figure 29; but the frequency of applications, up to seven times per month, suggests some type of deficiency. Algae could be adapting to these applications with vertical migrations to avoid lethal concentrations or by developing resistance. Also, dosages based on surface water analyses may be inadequate for effective control of subsurface algae. Further research is needed to assess the present application effectiveness and detect any deficiencies.

Selective withdrawal

Selective withdrawals can be used to increase dissolved oxygen concentrations in the hypolimnion (Olszewski 1961; Johnson and Berst 1965; Wirth et al. 1970; Stroud and Martin 1973). They also increase nutrient outputs if hypolimnetic nutrient concentrations are large compared to the rest of the water column (Wright 1967; Martin and Arneson 1978).

This technique could be a reasonable method to increase hypolimnetic dissolved oxygen concentrations in Mt. Dell Reservoir. Under anaerobic conditions, Mt. Dell Reservoir sediments released phosphorus at considerably higher rates than under aerobic conditions. Therefore, it is important to minimize hypolimnetic anoxia in order to reduce sediment P releases.

Aeration/circulation

Artificial aeration or circulation (whole lake mixing) can be a reasonably successful technique for controlling hypolimnetic anoxia and minimizing sediment nutrient releases (Pastorok et al. 1980). Algal biomass concentrations can also be controlled when mixing creates light limiting conditions (Lorenzen and Mitchell 1973). In addition, aeration induces changes in pH that can shift dominance in the algal community from blue-green species to green algae (Shapiro 1973). The disadvantages of the technique include increased turbidity and possible increased algal biomass if light does not become limiting (Fast 1979).

Figure 28 illustrates the dominance of blue-green species. Some of these cause more taste and odor problems than do green algae, and an aeration induced shift in algal species dominance could provide a more favorable food source for the zooplankton. Many aeration systems exist, and Fast (1979) should be consulted for further details on the types of systems available.

Sediment removal

Sediment removals are used to deepen lakes and remove contaminated or nutrient laden sediments. Peterson (1981) provided an excellent review of sediment removal as a lake restoration technique, and the following discussion is largely based on his review. He listed seven factors which should be considered in evaluating a sediment removal option.

His first step is to assess the problem. This study has already assessed the problem in limnological terms, and Mt. Dell Reservoir is in a mesotrophic-eutrophic state and has a present capacity that is approximately 91 percent of its potential. Also, the sediments can act as phosphorus sources under aerobic and anaerobic conditions (Table 14). Therefore, sediment removals might be a viable means to reduce sediment nutrient inputs and increase reservoir capacity.

The second and third considerations are to characterize the sediments and determine the sediment removal depth. Cluster analysis (Figures 5 to 8) detected differences between sediments which were dewatered annually and those which were rarely dewatered. These results suggest the possibility of only removing the sediments which are rarely dewatered since these contained the greater amounts of nutrients and organic matter.

Greater removal increases cost, but it also adds to a technique's effectiveness. The purpose of removal is to expose sediments which are lower in nutrient concentrations. If this technique is chosen, sediment cores should be collected and analyzed to determine an effective removal depth.

The fourth consideration is the environmental problems associated with sediment removal. Adverse effects include increased turbidity, possible resuspension of contaminants, increased nutrient concentrations in the water column, and possibly greater algal biomass if light is not limiting growth. Some of these problems could be inconsequential if dredging occurs during late fall or winter. The reservoir is not used for urban water supply during the winter, and turbidity and algal effects could be ignored. Increased nutrient concentrations could promote algal growth; but in the cases cited by Peterson, this was a short term phenomenon. Dredging can also disrupt or destroy benthic communities.

The last three considerations involve choosing removal methods and disposal areas and selecting a suitable time for sediment removal. Pierce (1970) described types of equipment and practical considerations. Selection of a disposal area could be discussed with Salt Lake City or County personnel. The most reasonable time to remove sediments is during late fall before surface ice has formed. Arrangements could be made so that use of Mt. Dell water is minimized during the dredging activities.

Phosphorus inactivation and precipitation

Phosphorus inactivation/precipitation has been a commonly used and reasonably successful method for controlling phosphorus concentrations in the water column and phosphorus sediment releases. The following discussion is largely based on reviews by Medine (1979), Cooke and Kennedy (1980), and Dunst et al. (1974).

The most widely used compound to inactivate or precipitate phosphorus is aluminum sulfate ($Al_2(SO_4)_3$). This compound generally removes phosphorus from the water column by precipitation. Phosphorus reacts with aluminum sulfate to form aluminum phosphate precipitates. Algae cannot utilize the phosphorus in these precipitates so the decrease of available phosphorus in the water column reduces algal biomass. Aluminum sulfate can also form aluminum hydroxides in waters with carbonate alkalinities. The resultant floc has sorptive capabilities, and phosphorus can be entrapped within this floc. These flocs effectively control sediment phosphorus releases when they cover the sediments and consequently lower the water column phosphorus concentrations if the sediments are a major phosphorus source.

The previously mentioned reviews cited numerous case studies, and the majority of these were successful in removing phosphorus from the water column. The degree of effectiveness usually varied with the dose and the specific situation, but most authors were satisfied with the overall result (an improvement in water quality and trophic state). Long term effectiveness studies are lacking (Cooke and Kennedy 1980), and it is unknown whether sediment phosphorus inputs can be minimized for long periods of time with this technique.

Side effects from aluminum sulfate additions vary and are undoubtedly dependent on the dose. Cooke and Kennedy (1980) cited one case where species diversity of planktonic microcrustacea was lowered but mentioned that most authors have not reported any adverse effects to biota other than algae.

Three effects of particular importance to water plant operators are the decreases of pH and alkalinity and the increase in dissolved aluminum (Medine 1979). All three changes, but especially an increase in dissolved aluminum, complicate water treatment operations.

To avoid these adverse effects, Kennedy and Cooke (1980) suggested doses which would reduce the pH to approximately 6.0. At this pH, phosphorus removal is optimized while undesirable side effects are minimized. The aluminum sulfate concentration required to obtain a pH of 6.0 depends on in-lake pH and alkalinity measurements, and Kennedy and Cooke (1980) provide a graphical means for estimating the proper dose concentration.

Since the critical phosphorus loading of Mt. Dell Reservoir occurred during spring runoff (Figures 32 and 33), phosphorus should be controlled at that time. Based on Kennedy and Cooke's dose estimation procedure and assuming the reservoir is at capacity, 620×10^3 kilograms ($\sim$684 tons) of $Al_2(SO_4)_3$ would be required for optimal treatment of the whole reservoir when pH and alkalinity are approximately 8.0 and 200 mg $CaCO_3/l$ respectively. If the uppermost 10 meters (the major zone of algal biomass) are treated, approximately 383×10^3 kilograms ($\sim$420 tons) would be required for optimum phosphorus removal. Considering the mass of $Al_2(SO_4)_3$ needed and the probable costs, treatment of the water column may not be a reasonable method of controlling algal biomass in Mt. Dell Reservoir.

Phosphorus inactivation would be a more reasonable approach if sediment phosphorus inputs are large. This study determined that sediment phosphorus inputs were less than 5 percent of the total annual phosphorus loading under aerobic conditions but increased to about 67 percent if anoxia occurred. This technique could be used to prevent sediment phosphorus releases to the overlying water, especially if the hypolimnion becomes anaerobic. Using the previously mentioned assumptions and estimation procedure, approximately 8500 kilograms (9 tons) would be required to treat the bottom 16 meters.

CONCLUSIONS

Watershed Nutrient Sources

1. Total phosphorus, orthophosphate, and total soluble inorganic nitrogen (TSIN) stream loadings ranged from 0.32 to 125, 0.13 to 33.7, and 0.88 to 231 kg/mo respectively and were usually highest during the spring runoff period.

2. Downstream areas of Parleys and Dell Creeks acted as nutrient sinks during late spring and summer while upstream areas generally acted as nutrient sources.

3. On an annual basis, the downstream area of Dell Creek contributed statistically significant amounts of TSIN to Dell Creek.

4. The upper left fork of Parleys Creek did not significantly contribute to stream nutrient loadings.

The Reservoir's Sediments

1. Frequently dewatered sediments contained lower total phosphorus, total nitrogen, and total organic carbon concentrations than do rarely dewatered sediments. Seep/spring area sediments contained higher concentrations of these nutrients than frequently dewatered sediments.

2. Statistical differences in total phosphorus areal flux between the two microcosm sediment types were not demonstrated.

3. The sediments contributed only a small fraction (<5%) to the total annual or summer total phosphorus load, but anaerobic conditions could increase sediment total phosphorus release to about 67 percent of the total annual phosphorus load.

The Reservoir's General Limnology

1. The reservoir was dimictic and exhibited weak summer stratification. Hypolimnetic oxygen depletion occurred, but anoxic conditions did not. Metalimnetic oxygen maxima occurred during the summer at depths of 6 to 9 meters.

2. The reservoir was alkaline with pH values typically about 8.0 and alkalinities usually around 200 mg $CaCO_3/l$.

3. Nutrient concentrations were generally highest during the fall and at greater depths.

4. Concentrations of algal biomass and numbers peaked during the winter and were often highest at depths of 6 to 9 meters.

5. Statistical differences among sampling sites were not demonstrated for total phosphorus, orthophosphate, total nitrogen, TSIN, and chlorophyll a. Measurement at a single station may be adequate to characterize Mt. Dell Reservoir given the variance in these measurements.

Limiting Nutrients

1. According to algal bioassays, water from the surface of Mt. Dell Reservoir and Parleys and Dell Creeks were limited by nitrogen or phosphorus throughout the year.

2. TN:TP and $TSIN:PO_4-P$ ratios indicated that the limitation is by

different nutrients at different seasons.

The Reservoir's Trophic State

1. Different trophic state indices described Mt. Dell Reservoir as oligotrophic, mesotrophic, and eutrophic. Those which indicated oligotrophy, however, were considered invalid because of hydrodynamic complications and the copper sulfate applications. Therefore, Mt. Dell Reservoir was considered to be in a mesotrophic/eutrophic state.

2. Vollenweider's (1976) loading model prediction of total phosphorus concentration at spring overturn was similar to the mean total phosphorus concentration measured at the end of spring overturn of 1981.

3. Vollenweider's (1976) loading model prediction of mean summer epilimnetic chlorophyll *a* concentration was different than the measured chlorophyll *a* concentration but approximated the measured concentration of uncorrected chlorophyll.

4. According to Vollenweider's (1976) equations, critical phosphorus loadings occurred during spring runoff.

RECOMMENDATIONS

Monitoring

1. This study has shown relatively high algal biomass levels at depths of 6 to 9 meters. Surface water collections do not account for this biomass. Similarly, Secchi transparency readings of this study did not extend below 4 meters and did not detect these algae. Therefore, water samples should be taken from interval depths extending to at least half of the maximum depth. The photic zone (0.1 percent surface illumination level) usually ends at approximately half of the maximum depth. Sampling to this depth would collect subsurface algal populations inhabiting the photic zone.

2. Algal identifications and enumerations are useful in detecting problem-associated algal species. These procedures should continue but should be extended to involve interval depth sample collection. However, visual observations should not be ignored because they may discover algal clumps and localized areas of algal growth.

3. Secchi disk measurements should be used as a gross indicator of water quality and trophic state. Measurements should be taken as frequently as possible throughout the year. The values could then be incorporated into Carlson's (1977) trophic state index to indicate seasonal or annual changes in trophic state on a numerical scale.

4. Water samples should be collected from the hypolimnion and analyzed for dissolved oxygen concentration (DO). Sediment phosphorus releases are enhanced by anoxia, and monitoring the hypolimnetic DO could reveal situations conducive to high sediment phosphorus release.

5. Total phosphorus and chlorophyll *a* concentrations could be used to indicate poor water quality conditions and algal biomass levels. Water samples could be sent to national or state certified laboratories for analyses, or the treatment plant operators could perform the analyses if the required equipment were available.

Restoration Techniques

1. Copper sulfate applications should continue to alleviate the problems caused by nuisance algae. However, the applications should be assessed to determine the most cost effective dose required for a particular situation.

2. Hypolimnetic withdrawals may curb hypolimnetic anoxia and consequently limit sediment P releases. If the hypolimnion becomes anoxic, water should be taken from the lowest port. Since all three outlets unite into a single conduit and silty water from the lower outlet withdrawals contribute to treatment costs, consideration should be given to bypassing water from the lowest port back to the stream. Anoxic waters could then be flushed out of the reservoir without complicating treatment plant operations.

During "dry" water years, all of the reservoir's water may be needed; and this technique may be of limited use. However, hypolimnetic withdrawals may still be used if sediment removal reduced siltation of the lower port. Then hypolimnetic water may be used by the treatment plant without extra water treatments caused by siltation.

3. Whole lake mixing by aeration could be a reasonable means of reducing

hypolimnetic anoxia. However, because of the weak stratification patterns of Mt. Dell Reservoir, a thorough mix may be difficult because the process is less efficient when the reservoir is near isothermal conditions.

4. Sediment removal is often a viable means of increasing reservoir capacity. However, the effectiveness of this technique for decreasing sediment phosphorus releases may be minimal since the sediments were generally not a major phosphorus source. Indeed, exposing sediments with unknown nutrient concentrations could be very risky. Therefore, sediment core samples should be collected and analyzed for total phosphorus, total nitrogen, and total organic carbon before the sediment removal technique is chosen.

5. Aluminum sulfate treatment for water column phosphorus inactivation and limitation of sediment phosphorus releases should be considered if water column and sediment phosphorus concentrations and releases are high. Monitoring hypolimnetic dissolved oxygen concentrations could indicate conditions which enhance sediment phosphorus release.

Further Research

1. Long term solutions to eutrophication are obviously the most appealing, and watershed management practices cannot be ignored. The results of this study suggested that the lower watershed area of Dell Creek contributed significant amounts of total soluble inorganic nitrogen (TSIN) to the creek. However, the division of the TSIN contribution between agricultural areas and undisturbed rangeland is unknown. Are the TSIN contributions to the creek due to surface runoff, subsurface water movements, or agricultural practices conducive to soil erosion? These are questions that must be answered before watershed management techniques can be applied. Monitoring surface runoff, groundwater movements and soil erosion could reveal which land use contributes more nutrients to Dell Creek. Although no significant differences in nutrient loading were found for the sampling sites on Parley's Creek, it is still unknown whether certain land uses are major nutrient contributors on a short term basis.

2. The cost effectiveness of various copper sulfate applications should be assessed. More effective and possibly economical doses may arise from such a study. The dosage rate of copper sulfate should depend on alkalinity, pH, temperature, dissolved organic matter, suspended particulates, and algal species tolerance and avoidance behavior. McKnight et al. (1981) outlined a relatively detailed bioassay technique to determine the copper tolerance levels of algae, and the reader is referred to this report for a detailed presentation of the technique. One simple method to determine avoidance behavior of algae and copper sulfate dispersal requires depth and time interval measurements of chlorophyll a, phaeophytin, and soluble and particulate copper. Beginning a day or two before copper sulfate is added, these parameters should be analyzed from water samples taken at appropriate depth and time intervals to determine background copper levels and normal vertical migration patterns of algae. Measurements of the same parameters should be taken during and after copper sulfate is applied. Changes in chlorophyll a, phaeophytin, and soluble and total copper through time or by depth should indicate algal migrations and copper dispersal patterns. Studies using this type of technique can be found in Button et al. (1977) and Effler et al. (1980).

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APPENDICES

Appendix A

Physical, Chemical and Statistical Analyses of Stream Sites

Table 22. Physical and chemical analyses for stream sites.

Site	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
Temperature (°C)															
DG	10.0	7.0	9.0	0.2	0.0	1.0	3.0	2.5	b	9.5	13.0	11.0	12.0	8.0	3.0
DUP	9.0	8.0	8.0	0.0	0.0	1.0	2.5	3.0	b	8.5	11.0	10.0			
PG	9.0	5.0	7.5	0.5	0.0	0.0	2.0	2.0	b	9.0	12.0	10.0	10.5	6.0	1.0
PGOLF	9.0	6.0	a	a	a	a	a	a	b	8.3	10.0	10.0			
PF	b	7.5	8.0	a	0.0	0.0	2.0	1.5	b	10.5	10.0	12.0			
LF	8.0	6.0	6.5	2.0	0.2	1.0	3.0	1.5	b	8.0	10.0	9.0			
Specific Conductance (μmhos/cm) (25°C corrected)															
DG	522	510	529	449	513	513	709	487	471	397	504	536	880	536	538
DUP	420	417	439	385	414	410	427	419	322	367	426	550			
PG	594	653	561	465	573	598	684	743	398	388	510	508	405	581	658
PGOLF	521	546	a	a	a	a	a	a	376	469	508	494			
PF	b	1237	1205	a	222	427	1538	1453	1020	822	1482	1274			
LF	506	452	488	504	496	513	530	496	347	391	444	471			
PO_4-P (mg P/l)															
DG	0.016	0.028	0.008	0.031	0.022	0.023	0.019	0.020	0.020	0.035	0.020	0.024	0.024	0.032	0.027
DUP	0.033	0.047	0.018	0.033	0.026	0.027	0.026	0.027	0.030	0.038	0.034	0.041			
PG	0.016	0.026	0.012	0.028	0.014	0.016	0.016	0.016	0.016	0.022	0.019	0.030	0.015	0.024	0.026
PGOLF	0.016	0.025	a	a	a	a	a	a	0.019	0.020	0.016	0.017			
PF	b	0.022	0.009	0.013	0.012	0.009	0.016	0.022	0.054	0.022	0.016	0.015			
LF	0.037	0.024	0.015	0.019	0.015	0.015	0.014	0.013	0.015	0.021	0.018	0.019			

[a] Samples were not taken because the site was inaccessible.

[b] Sample site was selected in October.

Table 22. Continued.

Site	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
TP (mg P/l)															
DG	0.021	0.032	0.026	0.032	0.022	0.053	0.020	0.052	0.047	0.046	0.027	0.031	0.024	0.032	0.036
DUP	0.033	0.054	0.035	0.033	0.026	0.068	0.026	0.063	0.090	0.043	0.053	0.064			
PG	0.021	0.034	0.026	0.028	0.014	0.044	0.020	0.044	0.062	0.057	0.050	0.030	0.021	0.037	0.050
PGOLF	0.016	0.069	a	a	a	a	a	a	0.099	0.038	0.035	0.026			
PF	b	0.040	0.026	0.020	0.012	0.036	0.022	0.063	0.265	0.034	0.025	0.022			
LF	0.037	0.034	0.029	0.020	0.015	0.050	0.015	0.030	0.051	0.041	0.029	0.046			
NH_3-N (mg N/l)															
DG	0.030	0.045	0.013	0.005	0.028	0.013	0.006	0.002	0.007	0.081	0.031	0.010	0.008	0.007	0.003
DUP	0.023	0.089	0.006	0.002	0.019	0.009	0.010	0.012	0.006	0.025	0.015	0.012			
PG	0.030	0.060	0.011	0.002	0.024	0.011	0.024	0.007	0.009	0.033	0.015	0.016	0.018	0.009	0.001
PGOLF	0.035	0.065	a	a	a	a	a	a	0.003	0.022	0.014	0.007			
PF	b	0.069	0.014	0.003	0.021	0.017	0.009	0.002	0.002	0.021	0.011	0.008			
LF	0.023	0.073	0.014	0.002	0.028	0.008	0.004	0.009	0.006	0.019	0.009	0.005			
(NO_2+NO_3)-N (mg N/l)															
DG	0.05	0.04	0.18	0.07	0.16	0.15	0.14	0.10	0.09	0.16	0.34	0.13	0.05	0.06	0.24
DUP	0.04	0.04	0.05	0.04	0.12	0.08	0.11	0.08	0.04	0.06	0.04	0.03			
PG	0.07	0.18	0.09	0.22	0.28	0.26	0.21	0.15	0.05	0.15	0.12	0.15	0.20	0.11	0.02
PGOLF	0.08	0.06	a	a	a	a	a	a	0.04	0.10	0.10	0.08			
PF	b	0.04	0.01	0.02	0.09	0.16	0.08	0.09	0.04	0.04	0.06	0.08			
LF	0.08	0.07	0.02	0.10	0.19	0.24	0.10	0.11	0.04	0.12	0.11	0.09			

[a] Samples were not taken because the site was inaccessible.
[b] Sample site was selected in October.

Table 22. Continued.

Site	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
							TSIN (mg N/1)								
DG	0.08	0.09	0.19	0.08	0.19	0.16	0.15	0.10	0.10	0.24	0.37	0.14	0.06	0.07	0.07
DUP	0.06	0.13	0.06	0.04	0.14	0.09	0.12	0.09	0.05	0.09	0.06	0.04			
PG	0.10	0.24	0.10	0.22	0.30	0.27	0.22	0.16	0.06	0.18	0.14	0.17	0.22	0.12	0.12
PGOLF	0.12	0.13	a	a	a	a	a	a	0.04	0.12	0.11	0.09			
PF	b	0.11	0.08	0.02	0.11	0.18	0.09	0.09	0.04	0.06	0.07	0.09			
LF	0.10	0.34	0.03	0.10	0.22	0.24	0.10	0.12	0.05	0.14	0.12	0.10			
							Organic Nitrogen (mg N/1)								
DG	1.1	0.8	1.8	1.2	0.6	0.0	0.2	0.2	0.9	0.7	0.0	0.3	0.2	1.5	0.0
DUP	1.6	0.9	1.1	0.8	0.4	0.3	0.2	0.1	0.3	0.6	0.0	1.0			
PG	1.4	2.0	1.3	0.9	0.4	0.3	0.1	0.1	0.9	0.5	0.2	0.2	0.6	1.5	0.3
PGOLF	0.8	0.8	a	a	a	a	a	a	0.6	0.5	0.3	0.0			
PF	b	0.6	1.3	0.6	0.6	0.0	0.1	0.4	0.8	0.2	0.0	0.0			
LF	0.7	0.9	1.7	0.9	0.3	0.2	0.2	0.1	0.8	0.4	0.0				
							Stream Flow (m^3/sec)								
DG	0.072	0.066	0.073	0.090	0.073	0.072	0.090	0.154	0.320	0.370	0.112	0.067	0.067	0.109	0.060
DUP	0.028	0.023	0.042	0.023	0.017	0.011	0.023	0.051	0.348	0.178	0.122	0.040			
PG	0.296	0.109	0.121	0.100	0.091	0.091	0.100	0.148	0.335	0.389	0.218	0.128	0.067	0.109	0.128
PGOLF	0.105	0.110	a	a	a	a	a	a	0.047	0.598	0.507	0.159			
PF	b	0.008	0.011	0.017	0.025	0.006	0.006	0.040	0.062	0.161	0.025	0.042			
LF	0.065	0.085	0.091	0.071	0.091	0.079	0.071	0.164	0.544	0.419	0.232	0.139			

[a] Samples were not taken because the site was inaccessible.
[b] Sample site was selected in October.

Table 23. Friedman's rank sum test of annual nutrient mass loading (at 95 percent level).[a]

A. Orthophosphate

Stream Sites	DG	DUP	PG	LF+PF	LF	PF
DG						
DUP	0					
PG	0	0				
LF+PF	0	+	0			
LF	0	0	0	0		
PF	0	0	+	+	+	

B. Total Phosphorus

Stream Sites	DG	DUP	PG	LF+PF	LF	PF
DG						
DUP	0					
PG	0	+				
LF+PF	0	+	0			
LF	0	0	0	0		
PF	+	0	+	+	+	

C. TSIN

Stream Sites	DG	DUP	PG	LF+PF	LF	PF
DG						
DUP	+					
PG	0	+				
LF+PF	0	+	0			
LF	0	0	0	0		
PF	+	0	+	+	+	

[a] + = significant difference in annual nutrient mass loading.

0 = significant difference not detected.

Appendix B

Chemical Concentrations of Mt. Dell Reservoir Sediments

Table 24. Chemical concentrations of Mt. Dell Reservoir sediments.

Site	Parameters			
	TOC mg/g	TN µg/g	TP µg/g	TAP µg/g
1	24.3	2002	848	69
	21.8	2002	1282	63
	18.9	1998	1302	a
2	10.3	1177	1286	30
	12.1	1062	1218	33
	12.4	1143	1226	a
3	6.40	770	898	26
	5.30	771	1088	27
	5.90	780	1092	a
4	4.30	517	1152	16
	5.90	372	1122	17
	2.20	389	1122	a
5	3.20	291	806	9
	11.7	430	882	10
	2.60	396	864	a
6	4.10	513	1206	17
	3.00	580	1244	17
	3.90	570	1222	a
7	7.80	754	1232	17
	5.70	771	1142	19
	6.80	822	1218	a
8	4.50	910	848	28
	4.00	844	1480	29
	4.30	874	1362	a
9	12.5	597	1260	33
	6.00	619	1488	36
	6.30	552	1472	a

[a] Sample was inadvertently not analyzed.

Table 24. Continued.

Site	Parameters TOC mg/g	TN µg/g	TP µg/g	TAP µg/g
10	28.6	1687	1978	36
	33.7	1755	1610	43
	27.7	1744	1758	a
11	4.70	536	966	24
	4.10	628	834	26
	4.30	537	1214	a
12	6.85	422	1156	14
	6.79	495	1172	17
	7.52	298	1168	17
13	10.8	1010	1364	21
	17.1	899	1434	24
	10.8	975	1422	20
14	18.6	2055	1904	18
	17.3	2116	1880	21
	23.4	2083	1908	22
15	21.1	2307	2034	25
	19.7	2136	2018	30
	19.6	2068	1998	20
16	22.6	2413	2096	16
	27.7	2461	2014	12
	24.7	2622	2088	12
17	23.7	2629	2010	11
	23.3	2372	2104	20
	18.9	2616	2092	15

[a] Sample was inadvertently not analyzed.

Appendix C

General Observations of the Microcosms and Algal Identifications

Table 25. General observations of the microcosms.

Date	Elapsed Days	Observations
Dec. 15	-	Microcosms filled with sediments. Oligochaetes visible in hypolimnetic sediments.
Dec. 16	-	Medium additions, water very turbid.
Dec. 18	-	Water still turbid but clearing.
Dec. 20	0	Microcosms sealed. Initial water samples taken and analyzed.
Dec. 23	3	Light/dark cycle started. Gas leaks suspected in dark microcosms. Oligochaetes not visible in HL3 anymore.
Dec. 26	6	Analysis day. Strong H_2S odor from HL3.
Dec. 29	9	ED2 leaking medium from the bottom of the microcosm, sealed with silicon sealant.
Dec. 30	10	H_2S odor from HL3 and no visible oligochaete activity. Sediments in HL3 dark brown to black in upper 1 cm.
Jan. 1	12	Analysis day.
Jan. 2	13	Separation of tygon tubing from acid bulb of HD2, break repaired. HL3 murky in appearance.
Jan. 5	16	H_2S odor and murky appearance still present in HL3.
Jan. 7	18	H_2S odor and murkiness clearing. HL2 and HL3 water faint green in color. Algae visible above sediments of EL2 and on the water stirrer of EL1. Analysis day.

Table 25. Continued.

Date	Elapsed Days	Observations
Jan. 10	21	Algae visible in all lighted microcosms. Oligochaetes active in all H microcosms except HL3.
Jan. 13	24	Analysis day. Algal mat forming on sediment surface in HL3.
Jan. 19	30	Analysis day.
Jan. 22	33	Filamentous algae much denser in EL microcosms but lessening in HL microcosms.
Jan. 25	36	Analysis day. Oligochaetes active again in HL3.
Jan. 31	42	Analysis day.
Feb. 3	45	Epilimnetic sediments all one color, brownish. HL3 brown in uppermost 0.5 cm and gray/black below. HL1 rust colored in uppermost 0.5 cm and gray/black below. HL2 from sediment top to bottom is brown, rust, gray, and black.
Feb. 6	48	Analysis day.
Feb. 12	54	Final analyses.

Table 26. Algal identifications from lighted microcosms.

Microcosm	Day 27	Day 54
EL1	Unknown Diatom *Synechococcus* *Scenedesmus*	*Navicula* *Anabaena* *Tribonema*
EL2	Unknown Diatom *Synechococcus* *Scenedesmus*	*Navicula* *Anabaena* *Tribonema* *Scenedesmus*
EL3	Unknown Diatom *Synechococcus* *Scenedesmus*	*Navicula* *Anabaena* *Tribonema*
HL1	Unknown Diatom *Synechococcus* *Scenedesmus*	*Navicula* *Scenedesmus* *Synechococcus*
HL2	Unknown Diatom *Synechococcus* *Scenedesmus*	*Navicula* *Synechococcus* *Scenedesmus* *Anabaena*
HL3	No Algae	*Scenedesmus* *Navicula* *Synechococcus*

Appendix D

Physical and Chemical Analyses of Mt. Dell Reservoir Waters

Table 27. Temperature (°C).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	19.1	13.8	6.7	1.0	1.0	0.3	1.5[a]	4.1	12.7	16.2	21.2	19.7	17.8	14.7	7.8
C3	18.7	13.5	6.6	3.0	2.3	1.5		4.3	12.3	14.0	20.2	19.7	17.7	15.0	8.0
C6	18.2	13.5	6.6	3.3	3.3	3.6		4.4	10.1	11.6	15.9	18.3	17.7	15.0	8.1
C9	17.8	13.5	6.5	3.5	3.5	2.6		4.4	9.1	10.3	13.8	16.7	17.7	15.0	8.1
C12	17.6	13.4	6.5	3.6				4.2	8.0	9.6	11.9	15.4	17.2	14.7	8.0
C15	17.4	13.3						3.6	6.9	9.2	11.0	14.4	17.1	14.7	8.1
C18	17.1							3.4	6.2	9.1	10.5	13.4	17.0		
C21	16.0							3.5	6.1	8.9	9.8	11.6			
C24										8.8	9.5				
C27										8.7	9.3				
JS	19.5	13.9	7.5						13.0	16.4					
J2			7.2						12.9	15.4	21.0	20.1			
J3	19.2	13.6	7.2						12.3	14.8	20.2	20.0			
J4									12.0	13.7	18.7	19.8			
J6	18.9	13.1							10.4	11.8	16.0	18.7			
J8									9.7	10.7	14.3	17.3			
J9	18.3								10.3	10.4	13.7	16.7			
J10									9.7	10.1	13.1	16.4			
J12	17.7								8.7	9.8	12.4	15.8			
J15										9.5		14.8			
PS	19.4	14.6							13.3	16.4	20.7	20.0			
PB	19.4	13.8							10.1	11.8	15.4	19.5			
DS	19.5	14.1							13.2	15.8	20.8	19.9			
DB	19.4	14.0							12.2	11.5	15.1	17.8			

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[a] Shoreline grab sample

Table 28. Dissolved oxygen (mg/l).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	14.0	7.3	10.0	13.3	10.4	10.8		14.0	8.8	9.0	8.7	8.7	8.2	8.4	9.9
C3	12.5	7.3	10.0	12.5	10.2	8.8				8.8	8.3	9.0	8.0	8.7	10.1
C6	13.4	7.2	10.1	11.4	8.0	7.5		11.2	10.0	10.2	12.8	8.9	8.0	6.3	10.0
C9	11.5	7.1	10.1	11.1	8.2	6.6		7.7	7.7	8.5	10.4	11.4	8.1	10.1	10.0
C12	10.5	6.8	10.3	10.3						7.8	8.3	9.3	6.7	8.0	10.0
C15	7.5	7.0						6.8	7.1	7.0	6.3	5.8	6.2	8.1	9.9
C18	8.6									7.3	5.3	4.5	5.8		
C21	2.5							5.6	6.0	7.2	4.9	3.3			
C24										7.0	4.6				
C27										6.8	3.9				
JS		7.4	10.2												
J2															
J3		7.6	10.3												
J4															
J6		7.7													
J8															
J9															
J10															
J12															
J15															
PS	15.3	7.6													
PB	15.5	7.6													
DS		7.9													
DB		7.8													

Table 29. pH.

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	8.4	8.2	8.1	8.2	8.2	8.2		8.2	8.1	8.2	8.2	8.3	8.3	8.3	8.2
C3	8.4	8.2	8.1	8.5	8.1	8.2		8.2	8.1	8.3	8.2	8.3	8.3	8.3	8.2
C6	8.3	8.2	8.1	8.2	8.0	7.9		8.2	8.0	8.3	8.4	8.3	8.3	8.3	8.1
C9	8.3	8.2	8.1	8.1	8.0	7.8		8.2	7.9	8.1	8.2	8.3	8.3	8.3	8.0
C12	8.3	8.1	8.1	8.0				8.1	7.7	8.0	8.0	8.1	8.1	8.3	8.0
C15	8.2	8.2						7.9	7.5	8.0	7.8	8.0	8.1	8.3	8.0
C18	8.2							7.8	7.5	8.0	7.7	7.7	8.1		
C21	8.2							7.8	7.4	7.9	7.6	7.5			
C24										7.9	7.6				
C27										7.9	7.5				
JS	8.4	8.3	8.1						8.0	8.3	8.2	8.3			
J2									8.0	8.3	8.2	8.3			
J3			8.1						8.1	8.3	8.2	8.3			
J4		8.4							8.0	8.3	8.2	8.3			
J6									7.9	8.1	8.2	8.2			
J8									8.0	8.1	8.1	8.1			
J9									7.9	8.1	8.1	8.1			
J10									7.8	8.1	8.1	8.1			
J12	8.4								7.8	8.1		8.0			
J15										8.1					
PS	8.5	8.4							8.0	8.3	8.2	8.3			
PB		8.3							7.9	8.2	8.1	8.2			
DS		8.3							8.0	8.3	8.2	8.3			
DB									8.0	8.1	8.1	8.1			

Table 30. Specific conductance (μmhos/cm) corrected to 25°C.

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	566	574	602	613	605	597	220[a]	616	500	534	544	560	592	607	650
C3	565	573	604	603	617	617		616	503	452	546	561	502	634	648
C6	569	574	605	616	637	643		615	501	442	532	560	502	634	650
C9	577	575	605	630	649	658		617	513	452	552	545	501	620	651
C12	579	578	606	646				645	552	452	527	545	507	614	653
C15	580	579						696	601	466	531	544	602	640	666
C18	585							743	630	468	551	571	604		
C21	581							752	632	474	474	562			
C24										474	470				
C27										478	472				
JS	558	574	597						498	454	546	564			
J2									501	455	544	562			
J3	560	573	602						504	452	549	562			
J4									501	458	594	563			
J6	564	571							490	442	563	576			
J8									490	442	577	576			
J9	571								491	446	572	581			
J10									495	444	553	584			
J12	574								510	446		581			
J15										454					
PS	564	567							494	538	543	571			
PB	565	574							470	570	489	590			
DS	561	570							491	456	460	563			
DB	562	571							479	416	553	482			

[a] Shoreline grab sample

Table 31. Total alkalinity (mg/l as $CaCO_3$).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	230	225	249	263	259	234	120[a]	230	190	190	188	193	213	210	216
C3	227	225	248	250	260	237		230	194	190	192	195	219	212	218
C6	221	221	246	249	259	244		228	192	193	192	192	215	210	219
C9	222	223	248	247	263	246		224	194	196	193	192	217	210	221
C12	224	212	246	245				232	200	195	192	191	216	206	216
C15	223	227						230	212	195	188	196	217	211	220
C18								250	224	198	194	198	219		
C21										194	196	198			
C24										195	193				
C27										196	193				
JS	222	228	244						192	194	192	195			
J2									192		190				
J3			245							198		187			
J4		228							194		195				
J6									190	198	195	198			
J8									192		197				
J9										197		198			
J10									202		194				
J12	223									199		196			
J15										193					
PS	222	225							192	195	194	200			
PB		230							188	104	198	194			
DS		225							196	193	190	193			
DB									194	108	206	205			

[a] Shoreline grab sample

Table 32. Total phosphorus (μg P/l).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	24	46	14	12	77	179	1169[a]	55	36	20	24	23	20	18	36
C3	28	50	19	48	26	60		53		28	25	22	21	25	33
C6	32	50	23	18	10	66		76		41	56	24	19	19	34
C9	32	50	15	22	18	79		44		62	39	27	21	19	35
C12	36	50	34	20				31		57	43	34	26	24	36
C15	47							24		34	36	43	34	24	55
C18								286		30	50	56	40		
C21										26	74	63			
C24										36	59				
C27										34	50				
JS	30	43	18							24	24	24			
J2											24				
J3			19							23		24			
J4		127									36				
J6										56	31	25			
J8											31				
J9										46		33			
J10											31				
J12	28									36		35			
J15										37					
PS	24	21								20	24	23			
PB		46								43	56	25			
DS		43								21	29	33			
DB										55	37	39			
Plant	35	119	13	31	15						46	27			

[a] Shoreline grab sample.

Table 33. Orthophosphate phosphorus (μg P/l).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	11	23	5	5	2	7	767[a]	2	2	9	9	9	10	1	8
C3	12	15	5	4	3	11		2		7	15	7	10	1	6
C6	16	18	5	6	2	7		1		7	8	6	19	0	13
C9	17	21	5	7	2	17		3		7	3	9	10	1	7
C12	21	31	7	7				7		6	2	10	15	4	7
C15	40	22						101[b]		5	6	26	18	3	9
C18										8	24	38	20		
C21										8	34	44			
C24										14	41				
C27										17	50				
JS	12	13	6							7	7	9			
J2											8				
J3			6							7		8			
J4		20									7				
J6										12	6	6			
J8											6				
J9										17		12			
J10											7				
J12	15									18		12			
J15										22					
PS	11	11								6	8	9			
PB		16								16	8	8			
DS		19								7	8	15			
DB										26	15	14			
Plant	25	19	5	6	4						25	23			

[a] Shoreline grab sample
[b] Bottom contamination

Table 34. Total soluble inorganic nitrogen (mg N/l), NH_3-N + (NO_2 + NO_3 - N).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	0.05	0.08	0.03	0.02	0.06	0.19		0.10	0.04	0.05	0.02	0.04	0.06	0.04	0.02
C3	0.08	0.06	0.03	0.02	0.35	0.20		0.10	0.04	0.07	0.03	0.02	0.03	0.03	0.01
C6	0.07	0.05	0.02	0.02	0.13	0.24		0.11	0.04	0.05	0.03	0.02	0.06	0.03	0.03
C9	0.04	0.09	0.02	0.01	0.22	0.67		0.07	0.05	0.07	0.03	0.02	0.08	0.02	0.03
C12	0.05	0.14	0.05	0.03				0.15	0.04	0.07	0.03	0.03	0.08	0.07	0.07
C15	0.16	0.61						0.22	0.05	0.08	0.04	0.04	0.05	0.02	0.02
C18								0.45	0.04	0.06	0.11	0.10	0.06		
C21									0.04	0.08	0.12	0.13			
C24										0.08	0.15				
C27										0.10	0.16				
JS	0.02	0.05	0.46						0.04	0.05	0.03	0.03			
J2									0.04		0.04				
J3			0.03							0.05		0.02			
J4		0.18							0.04		0.04				
J6									0.04	0.06	0.03	0.02			
J8									0.05		0.02				
J9										0.04		0.03			
J10									0.04		0.02				
J12	0.03									0.08		0.93			
J15										0.10					
PS	0.03	0.15							0.05	0.06	0.02	0.02			
PB		0.26							0.04	0.10	0.04	0.02			
DS		0.05							0.05	0.07	0.02	0.02			
DB									0.04	0.07	0.04	0.04			
Plant	0.08	0.14	0.03	0.01	0.16						0.11	0.05			

Table 35. Nitrate and nitrite ($NO_3 + NO_2 - N$) (mg N/1).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	0.02	0.02	0.02	0.02	0.04	0.18		0.10	0.04	0.04	0.01	0.03	0.05	0.03	0.02
C3	0.05	0.04	0.02	0.01	0.32	0.16		0.10	0.04	0.05	0.02	0.01	0.02	0.02	0.01
C6	0.01	0.01	0.01	0.02	0.11	0.15		0.11	0.04	0.04	0.02	0.01	0.05	0.02	0.02
C9	0.01	0.03	0.01	0.01	0.19	0.45		0.07	0.04	0.05	0.02	0.01	0.06	0.01	0.13
C12	0.02	0.02	0.03	0.03				0.14	0.04	0.05	0.02	0.02	0.07	0.05	0.02
C15	0.04	0.05						0.14	0.05	0.06	0.02	0.02	0.04	0.01	0.19
C18								0.12	0.04	0.04	0.07	0.03	0.04		
C21									0.04	0.05	0.05	0.06			
C24										0.05	0.06				
C27										0.05	0.07				
JS	0.01	0.03	0.45						0.04	0.03	0.02	0.02			
J2									0.04		0.03				
J3			0.01							0.03		0.01			
J4		0.06							0.04		0.04				
J6									0.04	0.04	0.03	0.01			
J8									0.04		0.01				
J9										0.03		0.02			
J10									0.04		0.01				
J12	0.01									0.06		0.92			
J15										0.06					
PS	0.01	0.01							0.04	0.03	0.01	0.02			
PB		0.15							0.04	0.08	0.03	0.01			
DS		0.02							0.04	0.03	0.02	0.01			
DB									0.04	0.05	0.04	0.04			
Plant	0.03	0.04	0.02	0.01	0.12						0.06	0.03			

Table 36. Ammonia (NH_3-N) (μg N/l).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	27	60	14	2	20	13	56[a]	3	3	14	9	11	8	8	0
C3	30	23	6	7	32	40		2	3	15	8	7	10	9	0
C6	58	43	8	2	24	85		4	1	14	7	8	9	9	1
C9	31	61	9	2	28	216		5	9	15	9	7	19	8	5
C12	26	120	19	2				14	2	18	9	11	8	16	1
C15	124	567						80	2	17	17	23	8	8	0
C18								330	2	22	43	70	17		
C21									2	27	68	66			
C24										32	87				
C27										48	90				
JS	13	23	5						3	15	7	9			
J2									3		8				
J3			15							16		6			
J4		118							3		4				
J6									2	22	2	4			
J8									6		5				
J9										14		7			
J10									2		8				
J12	21									22		7			
J15										38					
PS	18	140							6	26	7	3			
PB		107							1	22	7	8			
DS		30							6	35	4	8			
DB									3	18	3	2			
Plant	50	100	8	2	36						46	18			

[a] Shoreline grab sample

Table 37. Organic nitrogen (mg N/l), TKN- (NH_3-N).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	1.0	0.7	1.3	0.9	0.6	0.3	2.4[a]	0.2	0.8	0.5	0.2	0.7	0.2	1.0	0.3
C3	0.9	1.0	1.3	0.9	0.5	0.4		0.1	0.4	0.3	0.2	0.4	0.4	1.4	0.2
C6	1.1	1.2	1.3	0.7	0.6	0.0		0.2	0.6	0.4	0.4	0.4	0.3	1.2	0.3
C9	1.3	1.0	1.5	0.8	0.8	0.3		0.1	0.5	0.6	0.6	0.9	0.3	1.4	0.4
C12	0.3	1.4	1.5	0.5				0.0	0.0	0.4	0.5	0.6	0.2	0.9	0.4
C15	1.1	0.1						0.3	0.8	0.3	0.5	0.4	0.5	1.2	0.4
C18								0.5	0.0	0.4	0.5	0.7	0.7		
C21									0.3	0.4	0.6	0.2			
C24										0.3	0.8				
C27										0.3	0.6				
JS	1.1	1.2	1.2						0.0	0.5	0.3	0.2			
J2									0.0		0.6				
J3			1.6							0.2		0.7			
J4		0.6							0.0		0.4				
J6									0.0	0.1	0.4	0.0			
J8									0.6		0.5				
J9										0.5		0.9			
J10									0.4		0.4				
J12	1.0									0.3		0.2			
J15										0.2					
PS	1.2	0.8							0.0	0.3	0.5	0.7			
PB		0.8							0.2	0.3	0.5	0.6			
DS		0.8							0.0	0.3	0.2	0.5			
DB									0.1	0.5	0.5	0.5			
Plant	0.8	0.8	1.3	0.8	0.6						0.4	0.4			

[a] Shoreline grab sample

Table 38. Total nitrogen (mg N/l).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	1.05	0.78	1.33	0.92	0.66	0.49		0.30	0.84	0.55	0.22	0.74	0.26	1.04	0.32
C3	0.98	1.06	1.33	0.92	0.85	0.60		0.20	0.44	0.37	0.23	0.12	0.43	1.43	0.21
C6	1.17	1.25	1.32	0.72	0.73	0.24		0.31	0.64	0.45	0.43	0.42	0.36	1.23	0.33
C9	1.34	1.09	1.52	0.81	1.02	0.97		0.17	0.55	0.67	0.63	0.92	0.38	1.42	0.43
C12	0.35	1.54	1.55	0.43				0.15	0.04	0.47	0.53	0.63	0.28	0.97	0.47
C15	1.76	0.71						0.52	0.85	0.38	0.54	0.14	0.55	1.22	0.42
C18								0.95	0.04	0.46	0.61	0.80	0.76		
C21									0.34	0.48	0.72	0.33			
C24										0.38	0.95				
C27										0.40	0.76				
JS	1.12	1.25	1.66						0.04	0.55	0.33	0.23			
J2									0.04		0.64				
J3			1.63							0.25		0.72			
J4		0.78							0.04		0.44				
J6									0.04	0.16	0.43	0.02			
J8									0.65		0.52				
J9										0.54		0.93			
J10									0.44		0.42				
J12	1.03									0.38		1.13			
J15										0.30					
PS	1.23	0.95							0.05	0.36	0.52	0.72			
PB		1.06							0.24	0.50	0.54	0.62			
DS		0.85							0.05	0.37	0.22	0.52			
DB									0.14	0.57	0.54	0.54			
Plant	0.78	0.84	1.33	0.81	0.76						0.41	0.45			

Table 39. Uncorrected chlorophyll (μg/l).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	2.2	3.3	7.6	0.7	53.7	27.8		19.1	1.0	4.5	3.4	3.0	1.2	6.7	2.5
C3	2.2	8.6	9.6	30.7	19.3	1.6		8.4	6.8	8.3	3.5	24.0	3.2	4.6	1.4
C6	5.4	6.2	10.8	10.0	4.8	0.5		8.9	14.3	17.1	15.6	4.8	3.0	7.2	7.5
C9	4.6	3.5	12.8	8.3	4.0	0.3		17.0	17.3	19.8	3.6	0.8	1.4	4.7	3.7
C12	4.8	2.8	9.9	5.1				1.1	27.3	7.3	7.5	0.8	6.0	5.5	6.0
C15								1.2	24.1	13.8	1.0	14.4	5.4	8.1	6.7
C18								1.6	12.4	11.4	1.2	1.6	5.5		
C21									19.1	19.3	0.7	1.3			
C24										22.1	3.8				
C27										21.2	6.2				
JS	1.7	3.9	5.6						3.7	41.3	38.2	0.4			
J2									3.7		0.4				
J3			7.0							37.5		3.5			
J4		2.2							18.0		0.2				
J6									11.7	16.7	3.7	0.3			
J8									21.5		8.6				
J9										12.1		11.3			
J10									2.9		14.1				
J12										5.8		10.2			
J15										38.7					
PS	1.1	3.3							1.7	19.7	3.4	1.3			
PB		3.9							4.8	17.0	2.3	1.9			
DS		2.8							3.7	15.9	1.3	1.2			
DB									4.2	15.9	8.2	2.9			

Table 40. Chlorophyll a (μg/l), phaeophytin corrected.

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	0.9	1.5	3.3	0.3	36.8	10.9		8.2	0.4	1.9	0.5	0.0	0.4	3.0	1.0
C3	0.9	3.6	4.0	11.9	8.0	0.6		3.8	2.8	0.4	0.0	4.2	1.3	1.9	0.6
C6	2.2	2.7	5.3	4.0	1.8	0.1		3.6	5.7	2.3	0.0	0.0	1.0	3.1	3.2
C9	1.8	1.3	5.7	3.3	1.4	0.1		16.0	6.8	3.8	0.5	0.4	0.4	2.0	1.5
C12	2.0	1.2	4.0	2.2				0.4	10.8	1.5	0.0	0.1	2.4	2.5	2.7
C15		1.1						0.5	9.0	1.7	0.6	3.0	2.1	3.6	2.3
C18								0.5	5.0	5.6	0.5	1.0	2.1		
C21									14.7	2.5	0.5	0.3			
C24										2.8	0.7				
C27										2.8	2.0				
JS	0.8	1.4	2.3						1.6	2.5	0.6	0.2			
J2									1.6		0.1				
J3			3.0							1.2		0.8			
J4		0.9							6.8		0.1				
J6									4.7	2.4	0.0	0.3			
J8									8.6		1.7				
J9										2.0		2.8			
J10									0.5		1.9				
J12										1.2		1.5			
J15										9.6					
PS	0.5	1.4							0.7	2.4	0.7	0.1			
PB		1.7							1.9	3.8	1.0	0.1			
DS		1.2							1.5	0.0	0.3	0.0			
DB									1.7	3.1	2.0	0.1			

Appendix E

Summary of Statistical Analyses for Detecting Nutrient Concentration Differences between Reservoir Sites

Table 41. ANOVA analyses for nutrient spatial differences in Mt. Dell Reservoir, * = significant with $\alpha = 0.05$.

June (TP)

Source (S)	D.F.	S.S.	M.S.	F Ratio
Between Sites (T)	3	56.85	18.95	0.0933
Within Sites (E)	16	3250	203.1	
Total	19	3307		

July (TP)

S	D.F.	S.S.	M.S.	F Ratio
T	3	3662	1221	93.35*
E	16	209.2	13.08	
Total	19	3871		

August (TP)

S	D.F.	S.S.	M.S.	F Ratio
T	3	389.4	129.8	0.8860
E	13	1905	146.5	
Total	16	2294		

June (Ortho-P)

S	D.F.	S.S.	M.S.	F Ratio
T	3	156.9	52.31	1.530
E	16	547.3	34.20	
Total	19	704.2		

July (Ortho-P) Log Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.2518	0.0839	0.7353
E	16	1.825	0.1141	
Total	19	2.077		

August (Ortho-P) Log Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.1648	0.0549	0.7968
E	13	0.8952	0.0689	
Total	16	1.060		

June (TSIN) Log Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.0237	0.0079	0.5896
E	16	0.2141	0.0134	
Total	19	0.2378		

July (TSIN) Log Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.3771	0.1257	1.569
E	16	1.281	0.0801	
Total	19	1.658		

August (TSIN) Log Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.2661	0.0887	0.4151
E	13	2.778	0.2137	
Total	16	3.044		

Table 41. Continued.

June (TN) Log Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.0755	0.0252	1.385
E	16	0.2916	0.0182	
Total	19	0.3671		

July (TN) Log Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.0564	0.0188	0.5767
E	16	0.5221	0.0326	
Total	19	0.5785		

August (TN) Log Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.1684	0.0561	0.2488
E	13	2.931	0.2255	
Total	16	3.100		

June (Phaeophytin Corrected Chl) Log (X + 1) Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.0910	0.0304	0.6482
E	8	0.3751	0.0469	
Total	11	0.4661		

July (Phaeophytin Corrected Chl) Log (X + 1) Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.1030	0.0343	1.187
E	11	0.3183	0.0289	
Total	14	0.4213		

August (Phaeophytin Corrected Chl) Log (X + 1) Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.0530	0.0177	0.3627
E	11	0.3907	0.0488	
Total	14	0.4437		

June (Uncorrected Chl) Log (X + 1) Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.0910	0.0303	0.6461
E	8	0.3751	0.0469	
Total	11	0.4661		

July (Uncorrected Chl) Log (X + 1) Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.1030	0.0343	1.187
E	11	0.3183	0.0289	
Total	14	0.4213		

August (Uncorrected Chl) Log (X + 1) Transformed

S	D.F.	S.S.	M.S.	F Ratio
T	3	0.0530	0.0177	0.3627
E	8	0.3907	0.0488	
Total	11	0.4437		

Appendix F

Phytoplankton Enumerations of

Mt. Dell Reservoir Waters

Table 42. Mean counts of diatoms/ml from five subsamples.

Location	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
CS	1.4	18.2	1.8	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.2	0.0
C3	2.8	18.0	0.8	0.2	0.0			0.2	0.0	0.0	0.0	0.0
C6	1.2	22.0	0.4	0.2	0.2			0.2	0.0	0.8	0.4	0.0
C9	0.8	24.0	0.2	0.4	0.0			0.0	0.0	0.0	0.2	0.4
C12	2.8	11.8	0.0	0.0				0.0	0.0	0.2	0.0	0.4
C15	1.8	16.0	1.2					0.0	a	0.6	0.6	0.0
C18	1.4							0.0		a	0.0	0.0
C21										a	0.2	0.0
C24										a	0.0	
C27										a	0.2	
JS									a	0.0	0.0	0.0
J2									0.0		0.2	
J3										0.2		0.0
J4									1.0		0.8	
J6									0.2	0.0	0.6	0.2
J8									0.2		0.2	
J9										0.4		1.0
J10									2.0		0.4	
J12										0.2		1.0
J15										0.0		
PS									2.0	0.2	0.2	0.0
PB									1.6	0.2	0.8	0.0
DS									0.0	0.2	0.0	0.4
DB									2.0	0.2	0.4	1.2

[a] Samples mistakenly disposed

Table 43. Mean counts of flagellates/ml from five subsamples.

Location	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
CS	3.2	7.6	49.2	1.4	49.6	28.2	13.4	4.4	5.8	13.6	46.6	36.8
C3	3.4	7.0	56.4	14.4	6.0			2.6	5.6	14.6	54.8	0.6
C6	9.8	7.2	61.2	2.8	1.2			5.8	11.2	23.2	21.0	43.6
C9	14.2	5.4	56.4	2.6	0.0			0.6	12.0	19.8	28.6	2.2
C12	4.4	2.8	59.0	0.4				0.8	7.4	6.8	5.0	1.6
C15	2.4	4.2	7.2					0.6	[a]	4.8	1.6	0.2
C18	1.2							1.2		[a]	3.6	0.2
C21										[a]	1.0	1.4
C24										[a]	2.0	
C27										[a]	0.8	
JS									[a]	15.0	41.6	24.6
J2									0.4		58.6	
J3										18.0		0.8
J4									8.2		27.8	
J6									5.8	25.0	19.4	43.6
J8									5.0		15.4	
J9										18.0		10.8
J10									4.2		15.8	
J12										3.8		5.2
J15										0.8		
PS									0.2	16.2	41.8	0.6
PB									0.8	8.8	29.4	63.2
DS									0.4	16.0	46.4	35.2
DB									1.4	1.8	17.8	31.6

[a] Samples mistakenly disposed

Table 44. Mean counts of filamentous cells/ml from five subsamples.

Location	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
CS	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	6.2	7.0	2.0
C3	0.8	0.0	0.0	0.0	0.0			0.0	0.0	9.0	7.4	0.8
C6	0.8	0.2	0.0	0.0	0.2			0.0	0.0	3.6	11.0	0.8
C9	0.4	0.0	0.0	0.0	0.0			0.0	0.0	1.2	2.2	1.4
C12	0.6	0.0	0.0	0.0				0.0	0.0	0.6	1.0	0.0
C15	0.8	0.2	0.0					0.0	a	0.0	0.8	0.0
C18	0.4							0.0		a	1.4	0.0
C21										a	0.8	0.0
C24										a	0.2	
C27										a	0.0	
JS									a	4.0	7.6	0.0
J2									0.0		7.4	
J3										6.2		1.4
J4									0.0		9.6	
J6									0.0	3.2	7.6	0.4
J8									0.0		2.4	
J9										2.2		0.8
J10									0.0		1.6	
J12										0.8		1.0
J15										0.4		
PS									0.0	7.4	8.4	2.8
PB									0.0	1.8	8.2	1.8
DS									0.0	6.8	10.4	1.6
DB									0.0	3.2	5.6	1.2

[a] Samples mistakenly disposed

Table 45. Mean counts of the spherical type/ml from five subsamples.

Location	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
CS	56.0	79.4	69.4	16.4	170.3	111.0	43.4	70.4	50.6	15.0	53.2	19.4
C3	86.4	97.4	36.0	43.6	75.4			a	51.2	25.8	31.6	a
C6	52.6	105.8	38.6	17.4	-			35.4	58.8	42.8	38.4	15.2
C9	70.4	114.8	40.6	20.8	156.5			24.4	62.2	37.2	11.4	80.8
C12	a	a	20.8	22.4				54.0	60.0	a	13.6	a
C15	a	a	141.2					43.4	a	a	a	a
C18	a							75.4	a	a	9.4	25.4
C21								a		a	a	7.2
C24										a	a	
C27										a	a	
JS									a	18.4	15.8	15.4
J2									28.2		18.4	
J3										16.6		130.0
J4									39.2		23.2	
J6									43.4	69.0	15.2	18.4
J8									42.6		17.8	
J9										112.8		14.4
J10									66.4		14.2	
J12										75.6		7.6
J15										79.4		
PS									65.6	185.5	25.6	a
PB									41.8	135.0	72.6	29.0
DS									26.0	23.0	31.8	18.0
DB									31.4	48.8	21.0	19.8

[a] Samples degraded or mistakenly disposed

Appendix G

Algal Bioassay Maximum Standing Crops and Chemical and Statistical Analyses

Table 46. Algal bioassay MSC values (mg/l) for site DG.

Treatments	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A1	28.82	34.98	29.38	29.66	26.58	29.38	23.22	23.50	29.38	24.06	22.94	22.94
A2	25.74	35.26	35.54	29.66	44.22	30.50	23.50	23.22	25.46	23.78	22.10	20.98
A3	26.30	34.98	31.90	29.38	47.86	31.34	23.22	23.78	26.02	23.78	22.38	21.54
B1	37.78	34.98	42.82	46.46	43.66	27.98	22.94	23.50	27.14	40.86	29.38	27.98
B2	36.94	40.86	42.26	41.42	46.46	28.82	23.22	22.94	28.82	40.86	31.62	27.14
B3	36.10	38.90	43.10	47.58	45.34	30.22	24.34	23.50	28.54	41.98	31.34	27.98
C1	27.42	34.98	43.38	30.22	29.10	22.94	30.22	23.50	23.50	24.34	23.78	21.82
C2	28.26	35.54	36.66	29.38	27.42	22.94	32.18	23.50	23.78	24.34	23.22	21.54
C3	29.66	29.66	34.14	34.14	29.66	23.50	29.66	23.22	23.50	25.18	22.94	21.54
D1	92.38	80.34	90.98	100.8	103.3	94.62	63.26	48.70	51.78	90.70	74.74	79.22
D2	92.94	76.14	85.10	101.7	104.5	93.50	56.82	51.22	62.14	93.78	75.86	77.26
D3	94.06	82.86	90.70	94.34	102.2	90.70	55.14	58.50	64.94	92.94	85.66	77.82

Table 47. Algal bioassay MSC values (mg/l) for site PG.

Treatments	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A1	32.74	35.54	36.10	36.94	27.98	25.18	26.02	23.78	26.58	26.86	15.74	25.18
A2	32.46	34.14	39.46	36.38	28.54	25.46	26.02	23.50	27.14	25.74	15.74	24.62
A3	30.50	31.90	40.02	34.98	30.78	25.74	25.18	23.50	26.58	26.58	26.02	24.62
B1	35.54	41.42	35.26	43.66	31.90	26.58	24.34	23.22	26.02	37.78	30.78	15.74
B2	35.54	42.82	40.02	37.78	38.90	25.74	28.54	21.82	26.58	38.06	28.82	27.42
B3	36.10	42.54	43.10	40.02	31.62	25.74	34.14	22.10	27.42	38.06	29.10	23.50
C1	36.38	35.26	40.30	31.62	30.50	26.02	26.02	31.62	29.38	26.86	31.90	24.62
C2	33.86	36.94	49.82	31.90	29.10	25.18	24.34	30.22	25.74	27.70	31.34	24.34
C3	34.14	37.50	41.98	34.70	31.34	26.02	26.02	29.66	29.38	27.42	30.78	24.06
D1	102.2	90.70	92.38	78.66	103.3	79.50	85.38	51.50	76.98	96.86	90.42	82.30
D2	102.5	87.06	87.90	78.94	104.5	73.90	79.50	50.66	71.38	94.34	81.74	82.30
D3	99.66	82.02	90.70	88.74	102.2	83.14	73.62	54.30	78.10	101.7	123.7	82.02

Table 48. Algal bioassay MSC values (mg/l) for site C.

Treatments	Jan.	Feb.	Mar.[a]	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
A1	23.22	26.58	57.38	27.70	19.58	20.98	19.02	18.46	18.74	20.98	22.38	20.42
A2	14.34	29.38	45.90	27.70	19.58	20.14	19.30	18.46	18.46	21.26	22.38	19.30
A3	24.06	26.02	51.50	28.26	19.30	19.58	19.30	18.46	18.46	21.26	21.26	18.74
A+1	24.62	29.10	57.10	28.54	26.58	22.94	19.02	18.74	20.98	24.62	24.06	20.14
A+2	13.50	27.98	51.50	28.82	26.58	20.98	19.02	18.46	20.42	24.06	23.78	20.42
A+3	24.62	28.82	54.58	31.34	16.02	20.98	19.02	18.74	20.98	24.62	25.46	20.70
B+1	27.98	30.78	121.5	34.14	27.98	23.50	19.02	18.74	22.38	24.90	24.90	21.54
B+2	13.50	30.82	122.4	31.62	27.98	22.94	19.02	18.74	22.94	25.18	24.62	21.26
B+3	25.74	28.54	135.3	34.42	28.82	22.66	19.02	18.46	22.94	24.90	25.46	23.22
C+1	26.86	32.46	53.46	29.10	16.02	20.42	19.58	20.42	20.42	26.02	29.38	20.98
C+2	27.42	32.18	48.14	29.66	27.42	21.26	19.58	21.26	20.70	23.78	31.34	20.98
C+3	25.18	34.98	52.62	30.78	25.74	21.26	19.58	20.70	19.86	24.90	31.62	20.98
D+1	53.74	83.70	108.4	78.66	70.82	59.06	19.58	59.34	46.18	88.46	82.30	80.06
D+2	49.54	78.10	118.7	78.94	90.70	64.66	19.58	59.62	46.18	91.54	88.18	91.82
D+3	51.62	79.22	112.5	88.74	71.10	96.62	19.86	59.06	73.34	90.70	93.22	101.9

[a] Shoreline grab sample

Table 49. Algal bioassay results from Duncan's multiple range tests ($\alpha = 0.05$).[a]

		SITE C		
January				
Subset 1				
Group	GRP00	GRP01	GRP02	GRP03
Mean	23.8733	24.2467	25.7400	26.4867
Subset 2				
Group	GRP04			
Mean	51.6333			
February				
Subset 1				
Group	GRP00	GRP01	GRP02	
Mean	27.3267	28.6333	30.1267	
Subset 2				
Group	GRP02	GRP03		
Mean	30.1267	33.2067		
Subset 3				
Group	GRP04			
Mean	80.3400			
March				
Subset 1				
Group	GRP03	GRP00	GRP01	
Mean	51.4067	51.5933	54.3933	
Subset 2				
Group	GRP04			
Mean	113.1933			

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[a] Groups 00, 01, 02, 03, 04 are analogous to treatments A, A+, B+, C+, and D+ of reservoir water. Groups 01, 02, 03, 04 are analogous to treatments A, B, C, and D of stream waters.

Table 49. Continued.

March

Subset 3

Group	GRP02
Mean	126.3533

April

Subset 1

Group	GRP00	GRP01	GRP03
Mean	27.8867	29.5667	29.8467

Subset 2

Group	GRP01	GRP03	GRP02
Mean	29.5667	29.8467	33.3933

Subset 3

Group	GRP04
Mean	82.1133

May

Subset 1

Group	GRP00	GRP01	GRP03	GRP02
Mean	19.4867	26.3933	26.3933	28.2600

Subset 2

Group	GRP04
Mean	77.5400

June

Subset 1

Group	GRP00	GRP03	GRP01	GRP02
Mean	20.2333	20.9800	21.6333	23.0333

Subset 2

Group	GRP04
Mean	73.4333

Table 49. Continued.

July

Subset 1

Group	GRP01	GRP02	GRP00
Mean	19.0200	19.0200	19.2067

Subset 2

Group	GRP03	GRP04
Mean	19.5800	19.6733

August

Subset 1

Group	GRP00	GRP01	GRP02
Mean	18.4600	18.6467	18.6467

Subset 2

Group	GRP03
Mean	20.7933

Subset 3

Group	GRP04
Mean	59.3400

September

Subset 1

Group	GRP00	GRP03	GRP01	GRP02
Mean	18.5533	20.3267	20.7933	22.7533

Subset 2

Group	GRP04
Mean	55.2333

October

Subset 1

Group	GRP00
Mean	21.1667

Table 49. Continued.

October

Subset 2

Group	GRP01	GRP03	GRP02
Mean	24.4333	24.9000	24.9933

Subset 3

Group	GRP04
Mean	90.2333

November

Subset 1

Group	GRP00	GRP01	GRP02
Mean	22.0067	24.4333	24.9933

Subset 2

Group	GRP03
Mean	30.7800

Subset 3

Group	GRP04
Mean	87.9000

December

Subset 1

Group	GRP00	GRP01	GRP03	GRP02
Mean	19.4867	20.4200	20.6067	22.0067

Subset 2

Group	GRP04
Mean	91.2600

SITE DG

January

Subset 1

Group	GRP01	GRP03
Mean	26.9533	28.4467

Table 49. Continued.

January

Subset 2

Group	GRP02
Mean	36.9400

Subset 3

Group	GRP04
Mean	93.1267

February

Subset 1

Group	GRP03	GRP01	GRP02
Mean	33.3933	35.0733	38.2467

Subset 2

Group	GRP04
Mean	79.7800

March

Subset 1

Group	GRP01	GRP03
Mean	32.2733	38.0600

Subset 2

Group	GRP03	GRP02
Mean	38.0600	42.7267

Subset 3

Group	GRP04
Mean	88.9267

April

Subset 1

Group	GRP01	GRP03
Mean	29.5667	29.6600

Table 49. Continued.

<u>April</u>		
Subset 2		
Group	GRP02	
Mean	45.1533	
Subset 3		
Group	GRP04	
Mean	98.9133	
<u>May</u>		
Subset 1		
Group	GRP03	GRP01
Mean	28.7267	39.5533
Subset 2		
Group	GRP04	GRP02
Mean	39.5533	45.1533
Subset 3		
Group	GRP04	
Mean	103.3000	
<u>June</u>		
Subset 1		
Group	GRP03	
Mean	23.1267	
Subset 2		
Group	GRP02	GRP01
Mean	29.0067	30.4067
Subset 3		
Group	GRP04	
Mean	92.9400	

Table 49. Continued.

July

Subset 1

Group	GRP01	GRP02
Mean	23.3133	23.5000

Subset 2

Group	GRP03
Mean	30.6867

Subset 3

Group	GRP04
Mean	58.4067

August

Subset 1

Group	GRP02	GRP03	GRP01
Mean	23.3133	23.4067	23.5000

Subset 2

Group	GRP04
Mean	52.8067

September

Subset 1

Group	GRP03	GRP01	GRP02
Mean	23.5933	26.9533	28.1667

Subset 2

Group	GRP04
Mean	59.6200

October

Subset 1

Group	GRP01	GRP03
Mean	23.8733	24.6200

Table 49. Continued.

October

Subset 2

Group	GRP02
Mean	41.2333

Subset 3

Group	GRP04
Mean	92.4733

November

Subset 1

Group	GRP01	GRP03
Mean	22.4733	23.3133

Subset 2

Group	GRP02
Mean	30.7800

Subset 3

Group	GRP04
Mean	78.7533

December

Subset 1

Group	GRP03	GRP01
Mean	21.6333	21.8200

Subset 2

Group	GRP02
Mean	27.7000

Subset 3

Group	GRP04
Mean	78.1000

Table 49. Continued.

SITE PG

January

Subset 1

Group	GRP01
Mean	31.9000

Subset 2

Group	GRP03	GRP02
Mean	34.7933	35.7267

Subset 3

Group	GRP04
Mean	101.4333

February

Subset 1

Group	GRP01	GRP03
Mean	33.8600	36.5667

Subset 2

Group	GRP02
Mean	42.2600

Subset 3

Group	GRP04
Mean	86.5933

March

Subset 1

Group	GRP01	GRP02	GRP03
Mean	38.5267	39.4600	44.0333

Subset 2

Group	GRP04
Mean	90.3267

Table 49. Continued.

April

Subset 1

Group	GRP03	GRP01
Mean	32.7400	36.1000

Subset 2

Group	GRP01	GRP02
Mean	36.1000	40.4867

Subset 3

Group	GRP04
Mean	82.1133

May

Subset 1

Group	GRP01	GRP03
Mean	29.1000	30.3133

Subset 2

Group	GRP03	GRP02
Mean	30.3133	34.1400

Subset 3

Group	GRP04
Mean	103.3000

June

Subset 1

Group	GRP01	GRP03	GRP02
Mean	25.4600	25.7400	26.0200

Subset 2

Group	GRP04
Mean	78.8467

Table 49. Continued.

July

Subset 1

Group	GRP03	GRP01	GRP02
Mean	25.4600	25.7400	29.0067

Subset 2

Group	GRP04
Mean	79.5000

August

Subset 1

Group	GRP02	GRP01
Mean	22.3800	23.5933

Subset 2

Group	GRP03
Mean	30.5000

Subset 3

Group	GRP04
Mean	52.1533

September

Subset 1

Group	GRP02	GRP01	GRP03
Mean	26.6733	26.7667	29.1000

Subset 2

Group	GRP04
Mean	75.4867

October

Subset 1

Group	GRP01	GRP03
Mean	26.3933	27.3267

Table 49. Continued.

October			
Subset 2			
Group	GRP02		
Mean	37.9667		
Subset 3			
Group	GRP04		
Mean	97.6067		
November			
Subset 1			
Group	GRP01	GRP02	GRP03
Mean	25.8333	29.5667	31.3400
Subset 2			
Group	GRP04		
Mean	98.6333		
December			
Subset 1			
Group	GRP03	GRP01	GRP02
Mean	24.3400	24.8067	25.5533
Subset 2			
Group	GRP04		
Mean	82.2067		

Table 50. Algal bioassay control water chemical analyses.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Site C												
Total-P (mg/l)	0.077	0.179	1.17	0.055	0.036	0.020	0.024	0.023	0.026	0.018	0.036	0.038
Ortho-P (mg/l)	0.002	0.007	0.767	0.002	0.002	0.009	0.009	0.009	0.008	0.001	0.008	0.005
NO_3+NO_2-N (mg/l)	0.040	0.180	0.250	0.100	0.040	0.040	0.010	0.030	0.030	0.030	0.020	0.190
NH_3-N (mg/l)	0.020	0.013	0.056	0.005	0.005	0.014	0.009	0.011	0.014	0.008	0.00	0.013
TSIN (mg/l)	0.060	0.193	0.306	0.105	0.045	0.054	0.019	0.041	0.044	0.038	0.020	0.203
Soluble Copper (mg/l)	-	-	-	-	0.071	0.107	0.319	0.325	0.099	0.111	0.062	0.019
Site DG												
Total-P (mg/l)	0.022	0.053	0.020	0.052	0.047	0.046	0.027	0.031	0.030	0.032	0.036	0.027
Ortho-P (mg/l)	0.022	0.023	0.019	0.020	0.020	0.035	0.020	0.024	0.025	0.032	0.027	0.018
NO_3+NO_2-N (mg/l)	0.160	0.150	0.140	0.100	0.090	0.160	0.340	0.130	0.080	0.060	0.240	0.050
NH_3-N (mg/l)	0.028	0.013	0.006	0.005	0.007	0.081	0.031	0.010	0.031	0.007	0.001	0.007
TSIN (mg/l)	0.188	0.163	0.146	0.105	0.097	0.241	0.371	0.140	0.111	0.067	0.241	0.057
Site PG												
Total-P (mg/l)	0.014	0.044	0.020	0.044	0.062	0.057	0.050	0.030	0.026	0.037	0.036	0.017
Ortho-P (mg/l)	0.014	0.016	0.016	0.016	0.016	0.022	0.019	0.030	0.013	0.024	0.026	0.011
NO_3+NO_2-N (mg/l)	0.280	0.260	0.210	0.150	0.050	0.150	0.120	0.150	0.190	0.110	0.020	0.120
NH_3-N (mg/l)	0.024	0.011	0.024	0.007	0.009	0.033	0.015	0.016	0.014	0.009	0.003	0.007
TSIN (mg/l)	0.304	0.271	0.234	0.157	0.059	0.183	0.135	0.166	0.204	0.199	0.023	0.127

Table 51. TSIN:Orthophosphate and TN:TP ratios of algal bioassay control waters.[a]

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Site C												
TSIN:Ortho-P Ratios	30.0	27.6	0.40	52.5	22.5	6.00	2.11	4.56	5.50	38.0	2.50	40.6
TN:TP Ratios	8.57	2.73	2.32	5.45	23.3	27.5	9.17	32.2	13.0	57.8	8.89	-
Site DG												
TSIN:Ortho-P Ratios	8.55	7.09	7.68	5.25	4.85	6.89	18.6	5.83	4.44	2.09	8.93	3.17
TN:TP Ratios	35.9	3.02	17.5	5.77	21.3	20.4	13.7	14.2	10.8	49.1	1.94	-
Site PG												
TSIN:Ortho-P Ratios	21.7	16.9	14.6	9.81	3.69	8.32	7.11	5.53	15.7	4.96	0.88	11.5
TN:TP Ratios	50.0	13.0	16.0	5.91	15.5	11.9	6.80	12.3	39.0	43.8	8.40	-
Total Stream Loading												
TSIN:Ortho-P Ratios	32.4	14.7	11.0	7.17	4.43	7.38	11.3	5.73	7.17	3.39	3.95	5.42
TN:TP Ratios	59.8	8.07	16.7	5.69	17.9	15.6	8.35	13.0	24.0	46.2	6.75	-

[a] Weight ratios

Appendix H

Summer Water Densities of Various Strata in Mt. Dell Reservoir and Stream Sites DG and PG

Table 52. June water densities (mg/ml) of stream and reservoir waters.[a]

Depth (m)	Stream and Reservoir Site						
	DG	D	J	C	J	P	PG
0	1000.03	999.26	999.16	999.24	999.16	999.21	1000.03
3			999.41	999.53	999.41		
6		999.82	999.80	999.82	999.80	999.87	
9			999.95	997.27	999.95		
12			1000.00	1000.02	1000.00		
15			1000.03	1000.06	1000.03		
18				1000.07			
21				1000.08			
24				1000.09			
27				1000.10			

[a] Based on temperature and total dissolved solids concentration where total dissolved solids (mg/l) = 0.57 x specific conductance.

Table 53. July water densities (mg/ml) of stream and reservoir waters.[a]

	Stream and Reservoir Site						
Depth (m)	DG	D	J	C	J	P	PG
0	999.69	998.33	998.33	998.29	998.33	998.40	999.82
3			998.50	998.52	998.50		
6		999.43	999.29	999.29	999.29	999.34	
9			999.64	999.61	999.64		
12			999.64	999.84	999.64		
15				999.94			
18				1000.00			
21				1000.02			
24				1000.04			
27				1000.05			

[a] Based on temperature and total dissolved solids concentration where total dissolved solids (mg/l) = 0.57 x specific conductance.

Table 54. August water densities (mg/ml) of stream and reservoir waters.[a]

	Stream and Reservoir Sites						
Depth (m)	DG	D	J	C	J	P	PG
0	999.94	998.57	998.53	998.61	998.53	998.56	1000.02
3		998.93	998.59	998.61	998.59	998.99	
6			999.08	998.89	999.08		
9			999.24	999.16	999.24		
12			999.49	999.38	999.49		
15				999.52			
18				999.68			
21				999.89			

[a] Based on temperature and total dissolved solids concentration where total dissolved solids (mg/l) = 0.57 x specific conductance.

Appendix I

Hydrologic Data for Mt. Dell Reservoir and Its Inflowing Streams

Table 55. Mean monthly reservoir volumes (ac ft) from 1966 to 1980 and mean monthly total precipitation (inches). (Taken from Parley's Treatment Plant 1982.)[a]

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1966	1646	1925	1895	2160	2871	2983	2530	1854	1042	275	15	26
1967	77	94	341	804	1722	2786	2901	2606	2361	1926	1338	1044
1968	732	543	821	1307	2101	2912	2684	2290	2279	1687	1537	1739
1969	1671	1103	503	1072	2541	3099	2652	1810	1334	991	601	314
1970	310	499	783	1150	1713	2609	2929	2557	2255	2174	2481	2632
1971	2370	2224	1908	1448	2237	3069	2698	1792	983	819	1062	1144
1972	904	477	1074	b	2234	3079	2422	1632	990	673	891	998
1973	670	249	286	647	1944	3042	2738	2002	1487	1272	1060	1036
1974	811	534	491	878	2013	2914	2731	1854	1049	1061	1391	1398
1975	1104	594	407	335	289	1475	2803	2693	1851	1335	1259	1143
1976	829	595	826	750	1602	2827	2270	1134	493	531	914	1088
1977	1075	1279	1629	2108	2758	3006	2865	2632	2067	1520	1387	1387
1978	1144	755	723	748	1593	2821	2821	2389	2379	2270	1897	1803
1979	1456	894	608	768	2066	2904	2403	1842	1132	586	334	329
1980	747	1200	1037	648	1715	2842	2624	1982	1288	786	712	760
Mean volume	1037	864	889	1059	1960	2825	2671	2971	1533	1194	1125	1123
n	15	15	15	14	15	15	15	15	15	15	15	15
Mean Precip.	2.19	2.30	2.41	2.74	2.37	1.82	0.72	1.11	1.15	2.05	2.18	2.55

[a] Where 1 ac-ft = 1233.5 m and 1 inch = 2.54 cm

[b] Data unavailable

Table 56. Mean monthly flows (cfs) for Parleys Creek from 1966 to 1982. (Taken from Parley's Treatment Plant 1982.)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1966	3.50	3.30	5.80	12.30	18.50	13.10	7.10	5.10	4.20	3.90	3.40	3.20
1967	2.55	2.87	4.70	8.20	27.50	32.50	15.50	8.20	5.66	4.65	4.10	3.54
1968	3.43	3.73	5.10	10.10	28.40	32.60	15.10	9.20	5.70	5.20	5.30	4.00
1969	4.00	4.40	5.81	33.27	37.18	22.89	11.34	6.65	4.77	5.32	4.29	3.95
1970	3.90	b	5.05	6.80	29.00	28.20	15.10	7.60	6.30	5.30	5.20	5.10
1971	6.20	6.30	9.20	23.80	31.60	33.10	18.50	9.50	6.80	6.00	5.10	4.60
1972	4.53	4.82	19.72	29.60	37.78	28.63	13.88	12.40	9.76	6.35	5.13	3.83
1973	3.61	2.62	4.82	13.44	38.18	23.53	16.75	7.32	6.00	5.46	3.51	4.45
1974	3.61	3.06	13.53	25.91	44.38	28.98	13.64	7.49	4.46	3.09	3.57	3.39
1975	3.61	3.79	5.43	10.68	68.02	61.23	23.84	11.18	6.80	5.84	5.24	4.72
1976	3.54	4.53	6.34	19.10	31.46	18.58	9.81	6.01	4.21	4.09	3.44	2.72
1977	2.35	2.53	2.53	4.56	7.34	5.18	3.45	1.94	2.35	3.03	2.91	2.53
1978	2.59	2.67	10.74	31.19	40.21	33.17	15.24	7.98	6.10	5.09	4.80	4.28
1979	4.06	3.14	4.78	15.20	19.43	12.20	7.49	5.05	2.61	3.00	3.34	3.11
1980	4.12	4.32	5.05	20.96	32.56	23.24	12.68	6.94	5.38	5.01	4.27	3.39
1981	2.98	3.24	3.63	8.96	14.06	11.75	6.04	3.16	2.99	4.19	3.81	3.67
1982	3.34	5.56	12.22	28.98	a	a	a	a	a	a	a	a
Mean cfs	3.64	3.81	7.78	17.83	31.60	25.56	12.84	7.23	5.26	4.72	4.21	3.78
n	17	16	17	17	16	16	16	16	16	16	16	16

[a] Data was obtained before May 1982.

[b] Data unavailable.

Table 57. Mean monthly flows (cfs) for Dell Creek from 1966 to 1982. (Taken from Parley's Water Treatment Plant 1982.)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1966	2.60	3.00	8.10	20.80	22.10	5.90	2.20	1.10	1.30	1.70	2.10	2.30
1967	2.10	2.48	5.80	11.20	33.40	16.30	5.00	1.40	1.88	2.02	2.24	2.23
1968	2.37	3.23	6.20	16.70	40.40	19.70	5.40	4.00	2.70	3.00	3.30	2.90
1969	3.40	4.03	6.65	52.39	49.48	10.55	5.41	2.94	1.81	2.89	2.89	2.76
1970	3.10	b	4.71	10.30	53.10	18.00	5.20	2.40	2.50	2.90	3.50	3.50
1971	5.70	7.80	13.00	47.4	51.70	19.00	5.40	3.80	3.30	3.80	3.90	4.00
1972	3.95	4.77	32.96	46.45	54.84	18.05	5.57	4.16	4.00	3.75	3.72	3.16
1973	3.04	3.23	4.40	23.18	62.27	16.32	5.90	3.92	3.79	3.44	5.23	3.44
1974	2.93	2.77	13.49	44.06	77.25	21.19	6.44	4.12	3.04	4.06	4.65	4.22
1975	3.75	3.31	5.81	12.94	84.10	65.48	15.75	6.20	4.40	4.02	4.15	3.89
1976	3.45	3.84	6.00	21.41	28.78	8.56	4.02	2.57	1.93	2.35	2.43	2.30
1977	2.22	2.16	2.51	4.66	6.64	4.38	2.18	1.22	1.18	1.59	1.83	2.25
1978	2.08	2.12	14.56	44.24	70.08	26.71	8.11	3.46	3.07	2.96	3.00	2.87
1979	3.21	2.84	4.77	20.76	38.53	11.38	3.69	2.50	1.22	1.76	2.30	2.37
1980	2.95	4.26	5.89	35.94	49.39	17.89	6.15	2.62	2.43	2.35	2.75	3.09
1981	2.67	2.83	3.73	11.06	15.57	8.64	2.22	0.87	1.47	2.22	2.23	2.65
1982	2.58	4.80	11.25	28.28	a	a	a	a	a	a	a	a
x daily cfs	3.06	3.59	8.82	26.57	46.10	18.00	5.54	2.96	2.50	2.80	3.14	3.00
n	17	16	17	17	16	16	16	16	16	16	16	16

[a] Data was obtained before May 1982.

[b] Data unavailable.